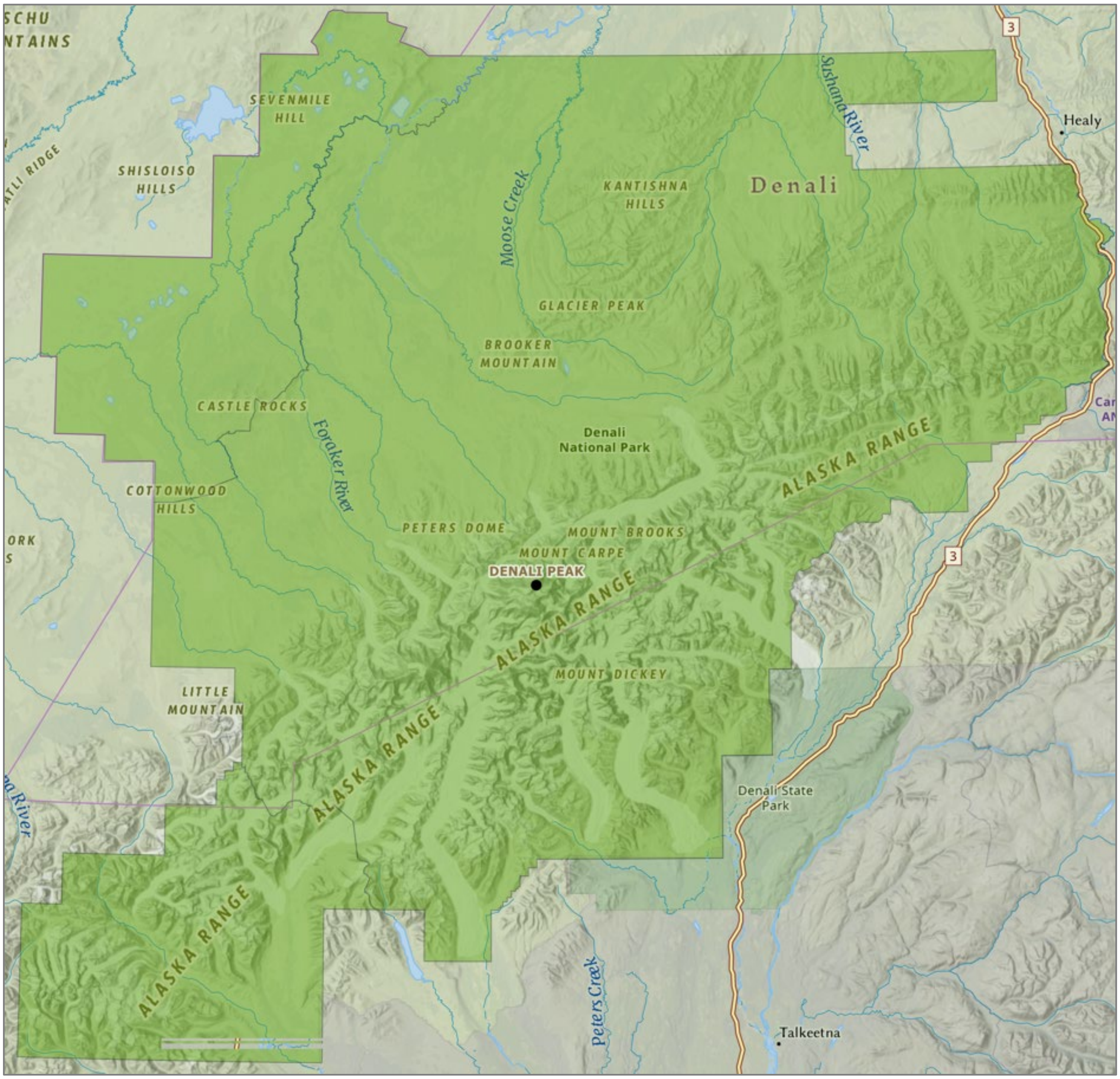
National Park Service
U.S. Department of the Interior

Science Report NPS/SR—2025/220
https://doi.org/10.36967/2307459

Exploring Spatial Patterns of Overflights at Denali National Park and Preserve



Map of Denali National Park and Preserve.

NPS / BRIAN PETERSON. MAP SERVICE LAYER CREDITS: STATE OF ALASKA, ESRI, TOMTOM, GARMIN, FAO, NOAA, USGS, EPA, NPS, USFWS

Exploring spatial patterns of overflights at Denali National Park and Preserve

Science Report NPS/SR—2025/220

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Please cite this publication as:

Peterson, B. A., J. M. S. Hutchinson, B. Gurung, D. H. Betchkal, and J. A. Beeco. 2025. Exploring spatial patterns of overflights at Denali National Park and Preserve. Science Report NPS/SR—2025/220. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/2307459

NPS 184/195998, February 2025

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Abstract

This study explored spatial patterns of overflights at Denali National Park and Preserve. Data were collected at Old Town Cantwell, Healy Radio Repeater, and K'esugi Ken Ranger Station. In total, overflights were analyzed from September 18th, 2021 to October 6th, 2022 (384 total days; 56 days of missing data) and May 25th, 2023 to September 13th, 2023 (112 total days; 0 days of missing data) using Automatic Dependent Surveillance-Broadcast (ADS-B) data. Phase 1 of the analysis focused on all overflights and revealed the transportation network of overflights above DENA. Phase 2 of analysis focused on low-level overflights that fly at or below 21,000 feet above mean sea level (MSL) and flew within 10 miles of the DENA boundary and found that the majority of waypoints were below 12,000 feet MSL. Phase 3 of analysis removed all overflights that were government flights, major airlines, and survey flights. The remaining flights were low-level overflights predominantly air tours. Kernel density analysis was conducted using waypoints segmented into 500 feet above ground level (AGL) altitude intervals. The altitude interval with the highest density of overflights was "0–500 feet AGL." This information can be used for planning and management purposes and this study serves as a resource for future research that intends to use more advanced analytics.

List of Acronyms

AGL: Above ground level

ADS-B: Automatic Dependent Surveillance-Broadcast

DEM: Digital Elevation Model

FAA: Federal Aviation Administration

GIS: Geographic information systems

DENA: Denali National Park and Preserve

MSL: Mean sea level

NPS: National Park Service

Acknowledgments

The authors would like to thank the National Park Service Natural Sounds and Night Skies Division for funding and supporting this project, and specifically Vicki Ward, Ashley Pipkin and Sharolyn Anderson for pre-submission reviews. Also, the authors would like to thank Dave Schirokauer from Denali National Park and Preserve for his help with pre-submission reviews. Additionally, the authors would like to thank Damon Joyce and Warren Deeds for their support of designing and building the logging units.

Introduction

Denali National Park and Preserve (DENA) was designated as a national park in 1917 (National Park Service, 2024) and is classified as a United Nations Educational, Scientific, and Cultural Organization (UNESCO) Biosphere Reserve (Cai et al., 2023). DENA is comprised of six million acres of subarctic land, spanning both southcentral and interior Alaska, transected by the Alaska Range (Cai et al., 2023). Its most well-known geological feature is Denali, itself, a mountain rising 20,310 feet above mean sea level (MSL). It is the highest mountain in North America (National Park Service, 2024) and is the third most topographically prominent summit on Earth. DENA is home to a variety of charismatic megafauna including grizzly bears, wolves, moose, and caribou. Wildlife viewing opportunities and the unique landscape attract about 600,000 summer visits per year (Fischer et al., 2023). The George Parks Highway extends access along the southern boundary of DENA. Buses transiting the Denali Park Road provide transportation through the northern part of DENA (private vehicles are not permitted on the road). The road parallels the Alaska Range and in normal operating conditions extends for 92 miles (National Park Service, 2024). In addition to transportation by bus, low-level overflights over DENA provide transportation to remote destinations within the unit as well as flight-seeing experiences.

The purpose of this report is to examine spatial patterns of overflights at DENA. As of January 1, 2020, the FAA requires all aircraft that enter designated airspace to be equipped with ADS-B technology (see 14 CFR § 91.225 and 14 CFR § 91.227) (FAA, 2023a). However, at DENA, ADS-B technology is only required when flying at or above 18,000 feet MSL (Federal Aviation Administration, 2023b). Regardless of the airspace designation, prior studies suggest a rather ubiquitous adoption of ADS-B by aircrafts in the United States (Peterson et al., 2022; Peterson et al., 2023).

ADS-B signals are transmitted from aircraft and provide location information and unique identifiers to improve airspace safety and air traffic efficiency. This study analyzed overflights above DENA that are equipped with ADS-B transmitter technology. The data discussed in this report were collected at Old Town Cantwell, Healy Radio Repeater, and K'esugi Ken Ranger Station (Table 1). Data collection at K'esugi Ken Ranger Station occurred twice from May 20th, 2022 to October 6th, 2022 and May 25th, 2023 to September 13th, 2023. In total, overflights were analyzed from September 18th, 2021 to October 6th, 2022 (384 total days; 56 days of missing data) and May 25th, 2023 to September 13th, 2023 (112 total days; 0 days of missing data) using Automatic Dependent Surveillance-Broadcast (ADS-B) data.

Table 1. Data collection dates, total days of data collection, and number of days with missing data for each ADS-B logger.

ADS-B logger location	Data collection dates	Total days data were collected	Days of missing data
Old Town Cantwell	9/18/2021–6/6/2022	262	0
Healy Radio Repeater	6/17/2023–9/12/2023	88	0
K’esugi Ken Ranger Station	5/20/2022–10/6/2022	140	56
K’esugi Ken Ranger Station	5/25/2023–9/13/2023	112	0

Methods

Data Collection

Data were collected by three ADS-B data loggers positioned at Old Town Cantwell (63.3951437, −148.9595150), Healy Radio Repeater (63.7385480, −148.9812649), and K’esugi Ken Ranger Station (62.5921523, −150.2311141) (Figure 1). The data loggers were positioned with an unimpeded and expansive skyward exposure and placed between 3 and 10 feet above ground. The loggers recorded ADS-B signals as text files.

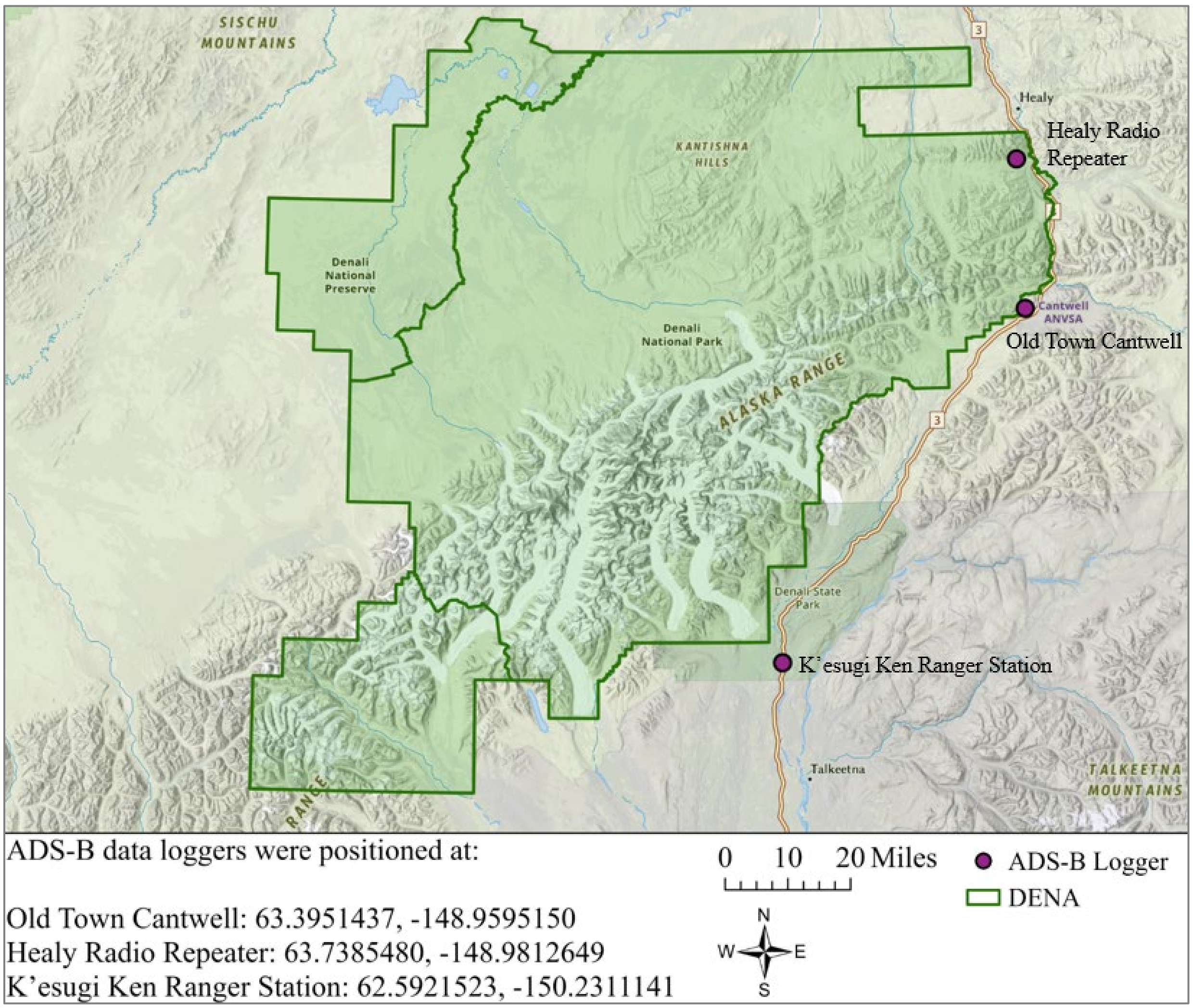

Figure 1. The three locations where ADS-B data loggers were positioned. NPS / BRIAN PETERSON

Data Processing and Cleaning

Data processing, cleaning, and analysis were accomplished using a custom ArcGIS Pro toolbox with multiple Python-based geoprocessing tools that automated and simplified processing and analysis of ADS-B data. The toolbox conducted the following tasks: processed raw ADS-B data files, removed repeated occurrences of waypoints collected by multiple data loggers, created waypoint and flightline feature classes ((spatial reference = North American Datum 1983 (2011) Alaska Albers (meters)), merged daily waypoints and flightlines, screened for suspected flights known not to be air tours (discussed in the next paragraph), conducted kernel density analysis, summarized waypoint altitudes, summarized number of flights across several temporal scales (monthly, daily, hourly), and summarized number of flights across aircraft types (rotorcraft, fixed-wing single engine, fixed-wing multi engine).

This report expresses altitude using mean sea level (MSL) and above ground level (AGL). Altitude expressed in MSL refers to the altitude of an aircraft above sea level, regardless of the terrain below it, whereas altitude expressed in AGL is a measurement of the distance between the ground surface and the aircraft. To calculate AGL altitudes for each waypoint, a 10-meter digital elevation model (DEM) was used (United States Geological Survey, 2021). The AGL altitudes were calculated by subtracting the reported altitudes of the ADS-B logger minus the elevation of the DEM for every point location (x,y) (see Beeco et al., 2020 for exact method).

ADS-B technology can use barometric altitude or geometric altitude. Barometric altitude is determined by measuring air pressure and must be regularly calibrated. Geometric altitude is calculated using the Global Positioning System (GPS). While error can result from each type of technology, GPS is generally considered a more reliable and accurate measure, but the aviation industry has long used barometric altitudes during flight. Aircraft owners/operators determine which system to use on their aircraft. The analysis in this report does not attempt to correct for any error associated with altitude information, as this would be nearly impossible and overly burdensome. Therefore, calculations of AGL can in some cases be negative. This can occur for low flying aircraft that have an ADS-B system reporting values lower than actual altitudes. Negative AGL calculations can also be due to an aircraft's ADS-B system malfunction. Further, AGL is calculated using 10x10m Digital Elevation Models (DEM). This level of resolution can also introduce some error. Negative AGL values are reported in the analysis. Finally, in some data sets MSL altitudes in the data are also negative. This is likely a system error. These data generally represent less than 0.1% of the data and are discarded from data analysis.

To explore spatial patterns of overflights at DENA, analysis was conducted in three phases. Phase 1 is a visual examination of all overflights within 10 miles of the park. Phase 2 reports altitudes using MSL, while Phase 3 uses AGL. This is because MSL is better suited for understanding aircraft patterns across a larger space or scale because the baseline (sea level) does not change. However, because Phase 3 includes more detailed examinations of the data, AGL analysis was used because it better contextualizes how flights pass over variable terrain and associated terrestrial resources and visitors' experiences. All maps produced during analysis used Esri basemaps with service layer credits for: State of Alaska, Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA, NPS, USFWS; and all data were projected to North American Datum 1983 (2011) Alaska Albers (meters).

Phase 1 Methods

The purpose of the first phase was to explore all overflight paths above DENA regardless of flight type. Thus, the flightline feature class was not cleaned of any flight types. To understand how flightpaths extended beyond the park boundary, a 10-mile buffer around the DENA boundary was used. One map was produced that showed all the data.

Phase 2 Methods

The purpose of the second phase was to understand low-level overflights above DENA regardless of flight type. Similar to Phase 1, a 10-mile buffer was used. Low-level overflights were identified as having an altitude less than 21,000 feet MSL. This altitude was chosen because the highest point at DENA is Denali at 20,310 feet MSL (National Park Service, 2024), and approximately 700 feet above the highest point would capture flights that had the greatest impact on the acoustic environment in the park. To understand flight altitudes, a waypoint feature class was used. Seven maps were produced which show low-level overflight waypoints across the following MSL altitudes: 1) 0–3,000 feet MSL; 2) 3,001–6,000 feet MSL; 3) 6,001–9,000 feet MSL; 4) 9,001–12,000 feet MSL; 5) 12,001–15,000 feet MSL; 6) 15,001–18,000 feet MSL; and 7) 18,001–21,000 feet MSL.

Phase 3 Methods

The purpose of the third phase was to remove flights known not to be either low-level overflights or air tours. The toolbox joined ADS-B data to the FAA Releasable Database via aircraft unique identifiers to determine aircraft tail number, type registrant (e.g., government), and engine type. Using this info along with ADS-B data, the toolbox screened for suspected flights known not to be either low-level overflights or air tours. by 1) cleaning the data of government flights, 2) major airlines, 3) straight-line flights, 4) flights with a flightpath less than a mile in length, and 5) survey flights. Government flights were identified as government aircraft (FAA Releasable Database type registrant = 5). Major airlines were identified using a list of major airlines (e.g., American Airlines, Delta Airlines, Alaska Airlines) input into the tool. Straight-line flights were assessed by calculating sinuosity values, which was used to identify any major airlines that were not listed in the prior step. Sinuosity is a measure of how much a linear feature deviates from a straight-line condition and can be calculated as the ratio of total flight path length to the straight-line distance between a flight's initial and final waypoint. A perfectly straight flight path would have a sinuosity of one, but as the number of meanders in the path increases (e.g., the characteristic back and forth of survey flight behavior) sinuosity will begin to approach zero. All overflights that received sinuosity values greater than or equal to 0.99 were visually inspected to validate straight-line paths were flown and these were subsequently removed from analysis. Flights less than a mile in length were removed due to data integrity issues. Lastly, survey flights were removed from analysis because of their undue influence on analysis, infrequent nature, and known flight purpose. Survey flights were clearly identifiable by their flight patterns. Removal of survey flights was the last cleaning procedure because this step requires visual analysis which is easier to conduct after the other cleaning procedures have been accomplished. Survey flight behavior can be identified when a flight route consists of consecutive back and forth lateral movements in a parallel progression. Conversely, air tour behavior generally consists of flight routes that veer toward sightseeing locations and consist of sporadic S-turns and loops (Beeco & Joyce, 2019). After this cleaning step, the remaining flights are more likely to be low-level overflights and air tours, but without cross checking with every operator or plane owner, a definitive confirmation that all remaining flights are low-level overflights including air tours is not possible.

Consistent with other aircraft tracking reports, a 0.5-mile buffer around the park was used for Phase 3 to understand spatial patterns of low-level overflights that likely have the biggest impact on DENA's acoustic environment. Using a 500ft AGL altitude interval, waypoint data were segmented (<0 feet; 0–500 feet AGL; 501–1,000 feet AGL; 1,001–1,500 feet AGL; 1,501–2,000 feet AGL; 2,001–2,500 feet AGL; 2,501–3,000 feet AGL; 3,001–3,500 feet AGL; 3,501–4,000 feet AGL; 4,001–4,500 feet AGL; 4,501–5,000 feet AGL) and kernel density analysis was conducted for each altitude interval. Because each altitude interval had different density results, density classifications were normalized across altitude intervals. To do this, the altitude interval with the highest maximum density of waypoints (0–500 feet AGL) was used to normalize density classification, which required two steps. First, the 0–500 feet AGL altitude density was classified using equal interval percentage breaks with five intervals of 20%. These percentage breaks were determined using the maximum density per square kilometer as the "100%" value. Second, the maximum density was segmented across five 20% equal interval classifications. Finally, the resulting density classifications were applied to the other altitude intervals. These steps are necessary to ensure density was calculated the same across altitude intervals regardless of the number of waypoints.

Next, the analysis focused on exploring AGL and MSL waypoint trends. For AGL altitude trends, analysis mapped waypoints less than 0 feet AGL, between 0 to 2,500 feet AGL, and between 2,501 to 5,000 feet AGL. For MSL altitude trends, analysis mapped waypoints between 0 to 5,250 feet MSL, between 5,251 to 10,500 feet MSL, 10,501 to 15,750 feet MSL, and between 15,751 to 21,000 feet MSL. Because the elevation of Denali is 20,310 feet MSL (National Park Service, 2024), that elevation was used to inform analysis of MSL altitude waypoint trends up to 21,000 feet MSL.

Descriptive analyses were conducted to understand waypoint frequencies across AGL and MSL altitudes; number of flights across months, days of the week, and hours of the day; and number of flights across aircraft types. Next, to gain insight into overflight travel patterns across aircraft types, analyzes were conducted to understand spatial patterns for fixed-wing single engine aircraft, fixed-wing multi engine aircraft, and rotorcraft aircraft. Lastly, spatial patterns of administrative flights were explored.

Results

Results—Phase 1

The research team mapped overflights for all flights (*n*=39,690). Figure 2 shows several distinct travel corridors. Areas with opaque lines indicate where there is greater flight density.

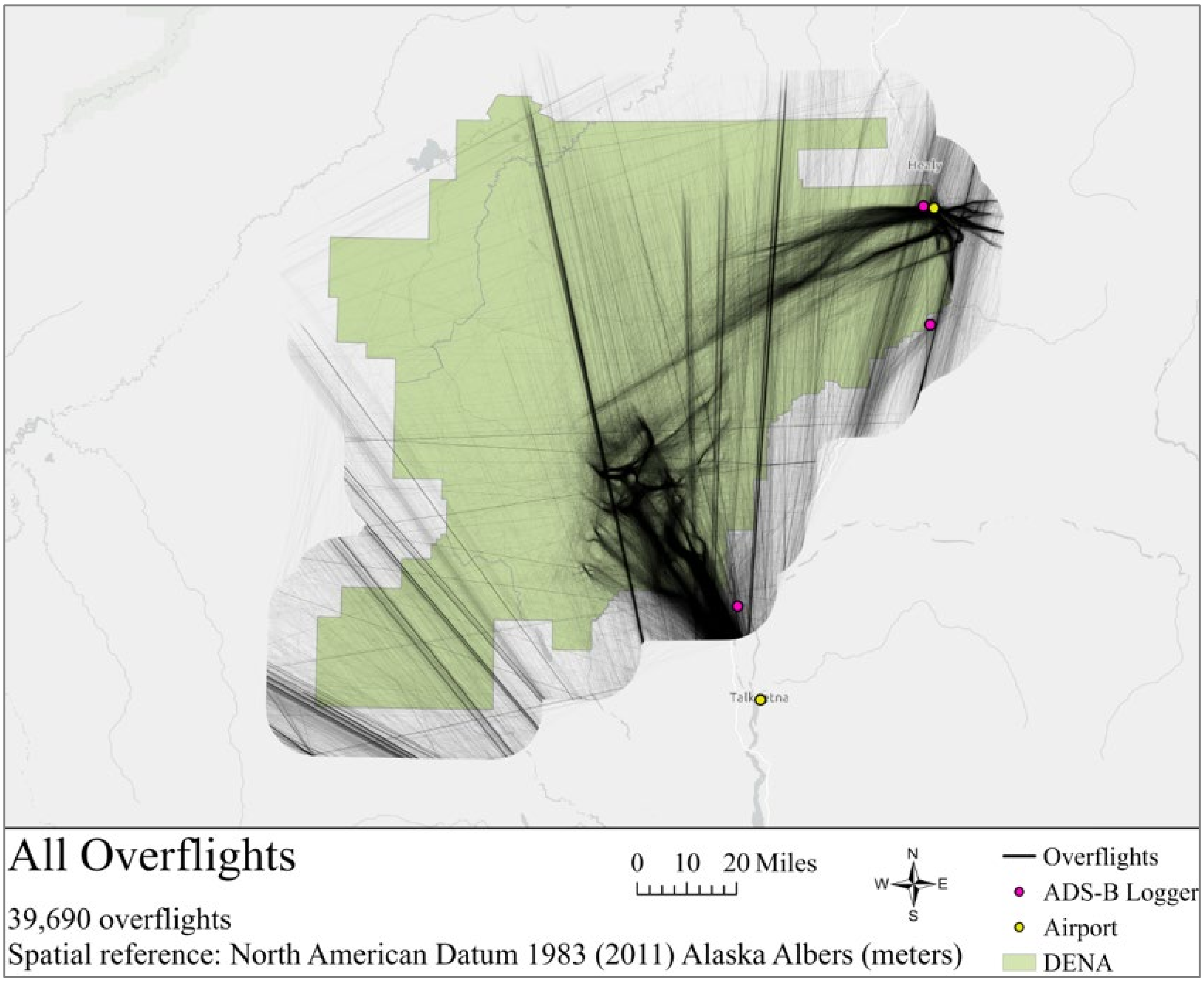

Figure 2. All overflights. NPS / BRIAN PETERSON

Results—Phase 2

The research team mapped waypoints for all overflights that flew between 0 and 21,000 feet MSL (13,774,495 total waypoints), which is displayed across seven figures. Also, these figures display DENA's Backcountry Management Plan soundscape zones which are defined by levels of natural sound disturbance (National Park Service, 2006). Low natural sound disturbance is defined as "natural sounds predominate in this area and motorized noise intrusions are very rare and usually faint." Medium sound disturbance is defined as "natural sounds predominate in this area, but there are infrequent motorized intrusions, a few of which may be loud." High natural sound disturbance is defined as "natural sounds are frequently interrupted by motorized noise, including some loud noise."

Very high natural sound disturbance is defined as "natural sounds are often interrupted by motorized noise including loud noise."

- Figure 3 shows waypoints between 0 and 3,000 feet MSL (2,277,079 waypoints).
- Figure 4 shows waypoints between 3,001 and 6,000 feet MSL (4,543,329 waypoints).
- Figure 5 shows waypoints between 6,001 and 9,000 feet MSL (3,785,110 waypoints).
- Figure 6 shows waypoints between 9,001 and 12,000 feet MSL (1,968,156 waypoints).
- Figure 7 shows waypoints between 12,001 and 15,000 feet MSL (492,522 waypoints).
- Figure 8 shows waypoints between 15,001 and 18,000 feet MSL (270,909 waypoints).
- Figure 9 shows waypoints between 18,001 and 21,000 feet MSL (437,390 waypoints).

These figures show that most waypoints are below 12,000 feet MSL. These waypoints are likely from flights connecting the complex of airports within and adjacent to the DENA frontcountry. Waypoints between 15,001 feet and 21,000 feet MSL are likely from overflights passing over the park, except for a pattern of waypoints that encircle the Denali massif.

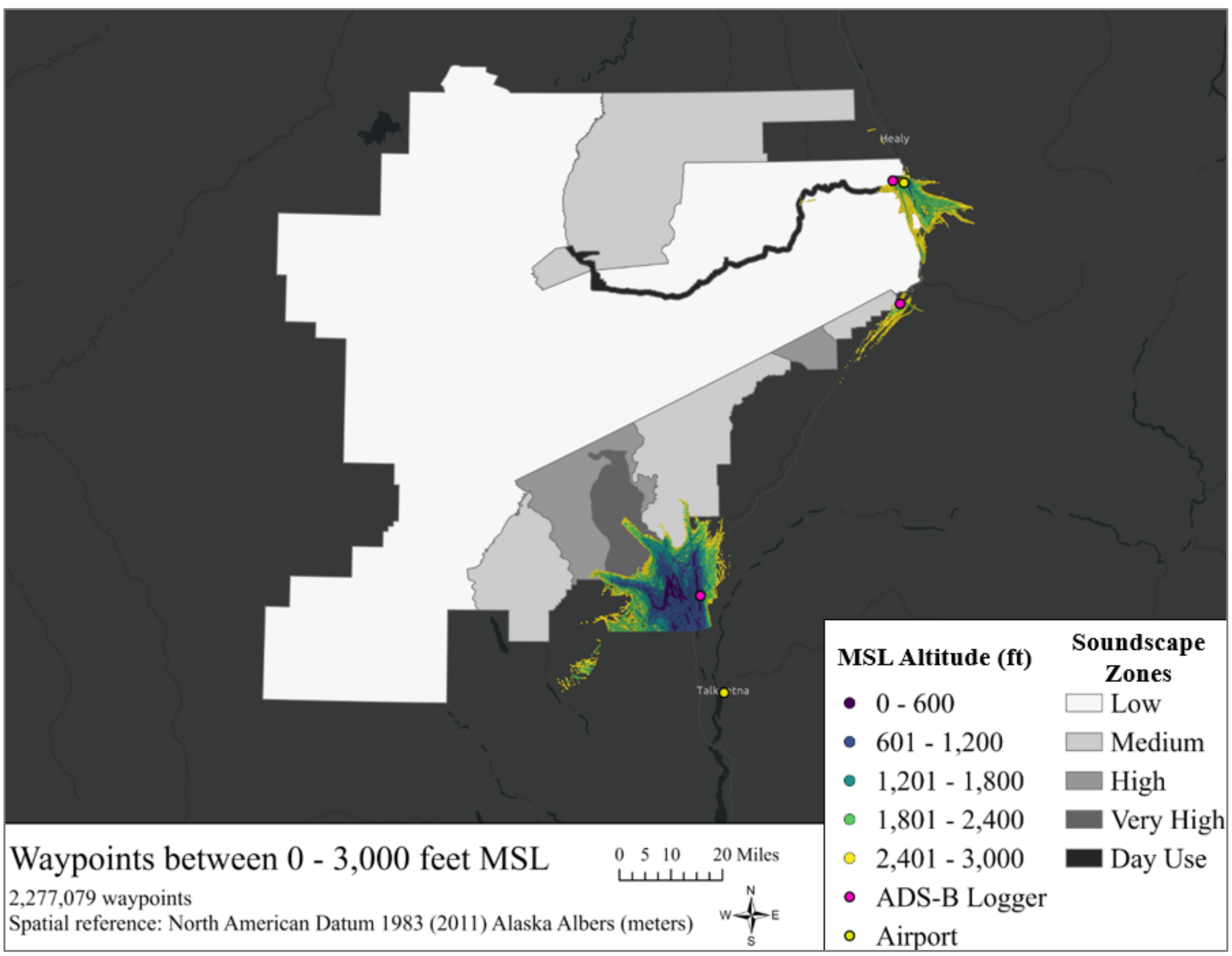

Figure 3. Waypoints between 0 and 3,000 feet MSL. NPS / BRIAN PETERSON

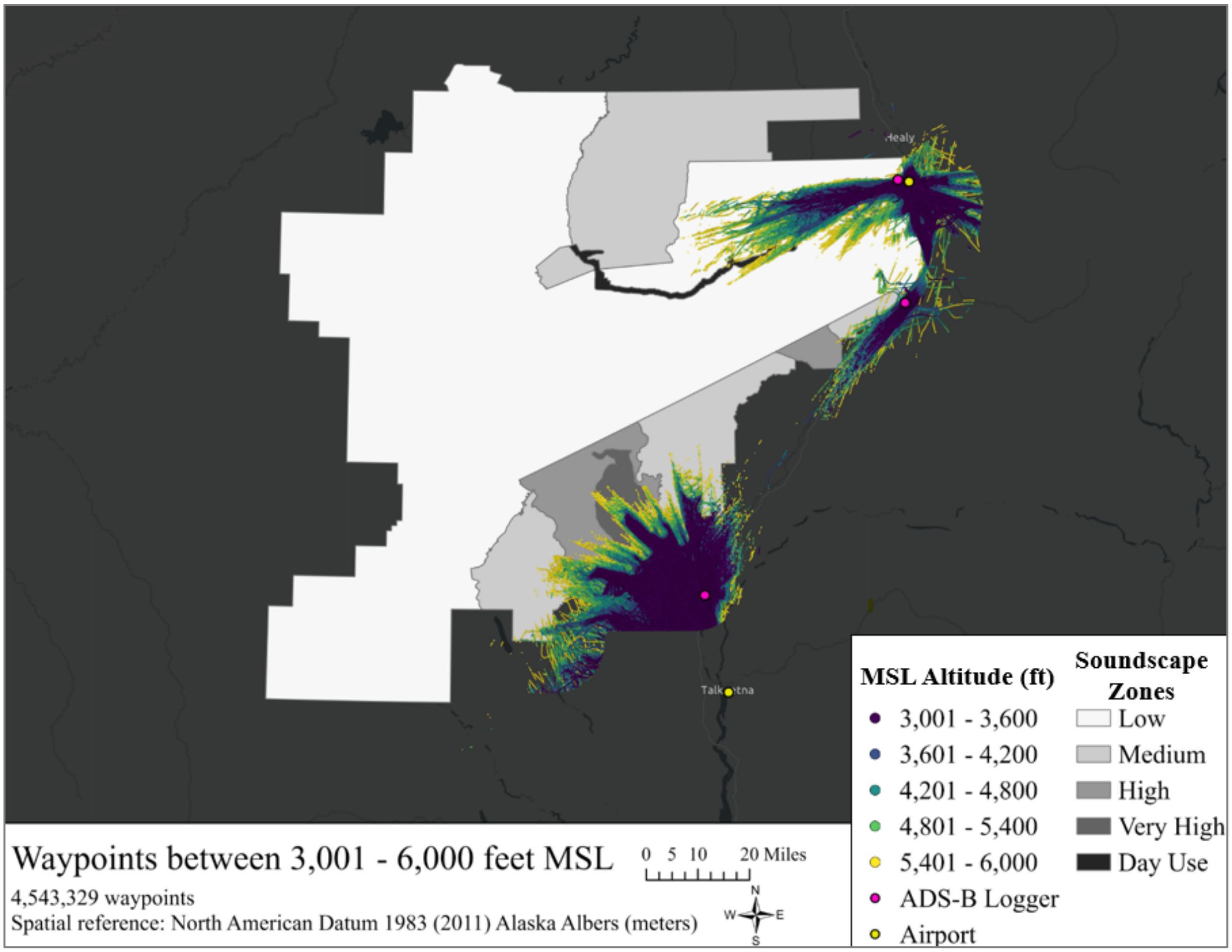

Figure 4. Waypoints between 3,001 and 6,000 feet MSL. NPS / BRIAN PETERSON

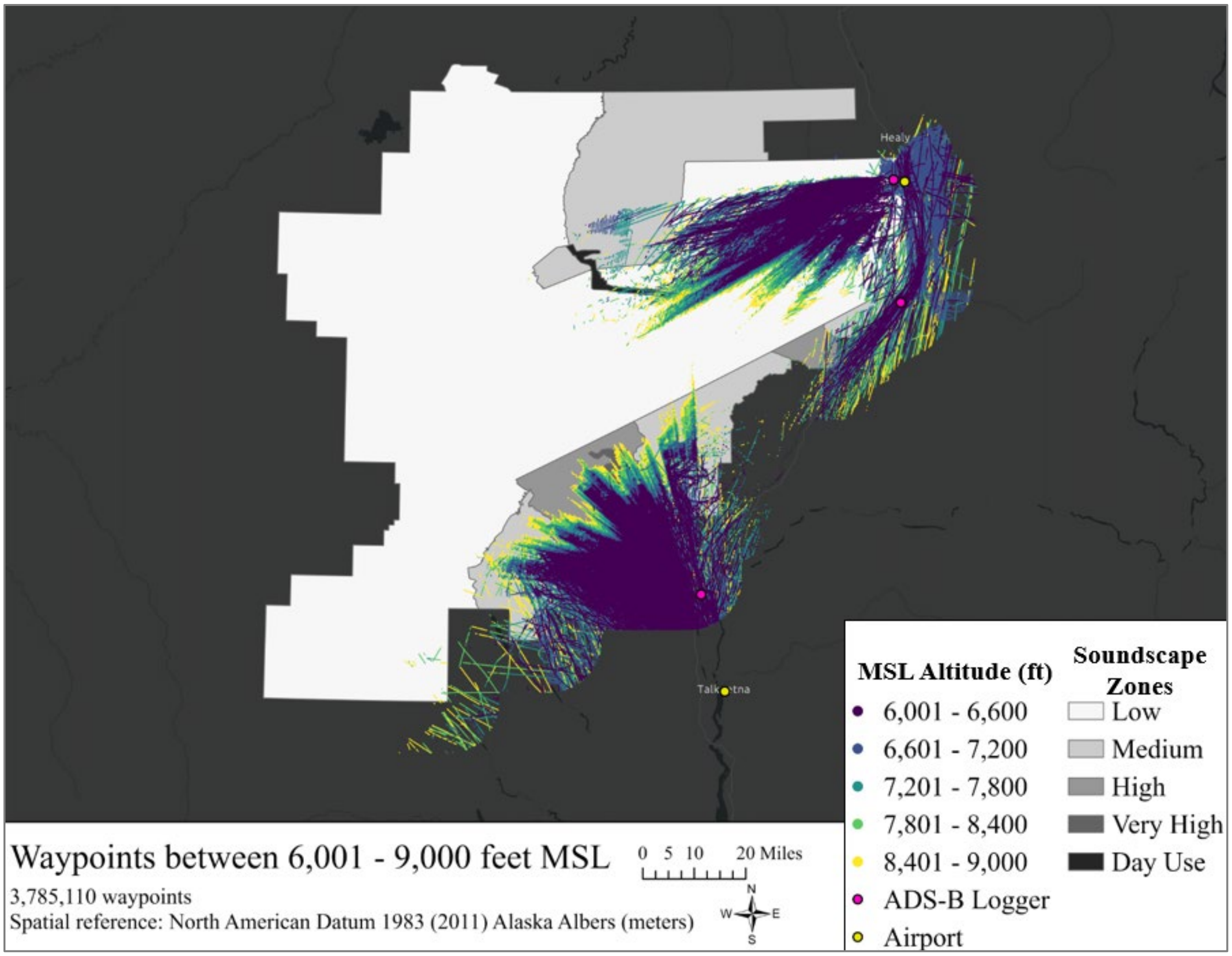

Figure 5. Waypoints between 6,001 and 9,000 feet MSL. NPS / BRIAN PETERSON

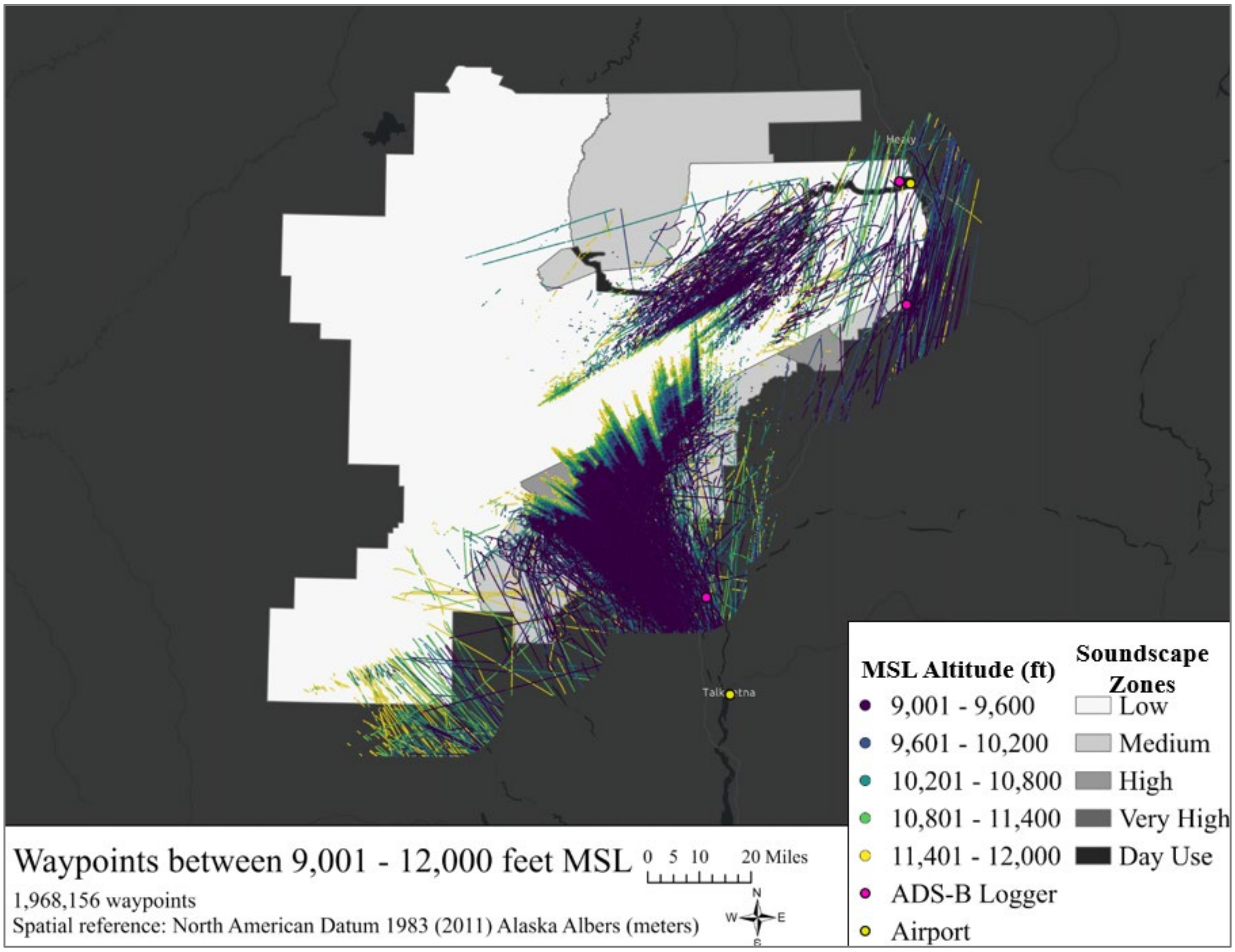

Figure 6. Waypoints between 9,001 and 12,000 feet MSL. NPS / BRIAN PETERSON

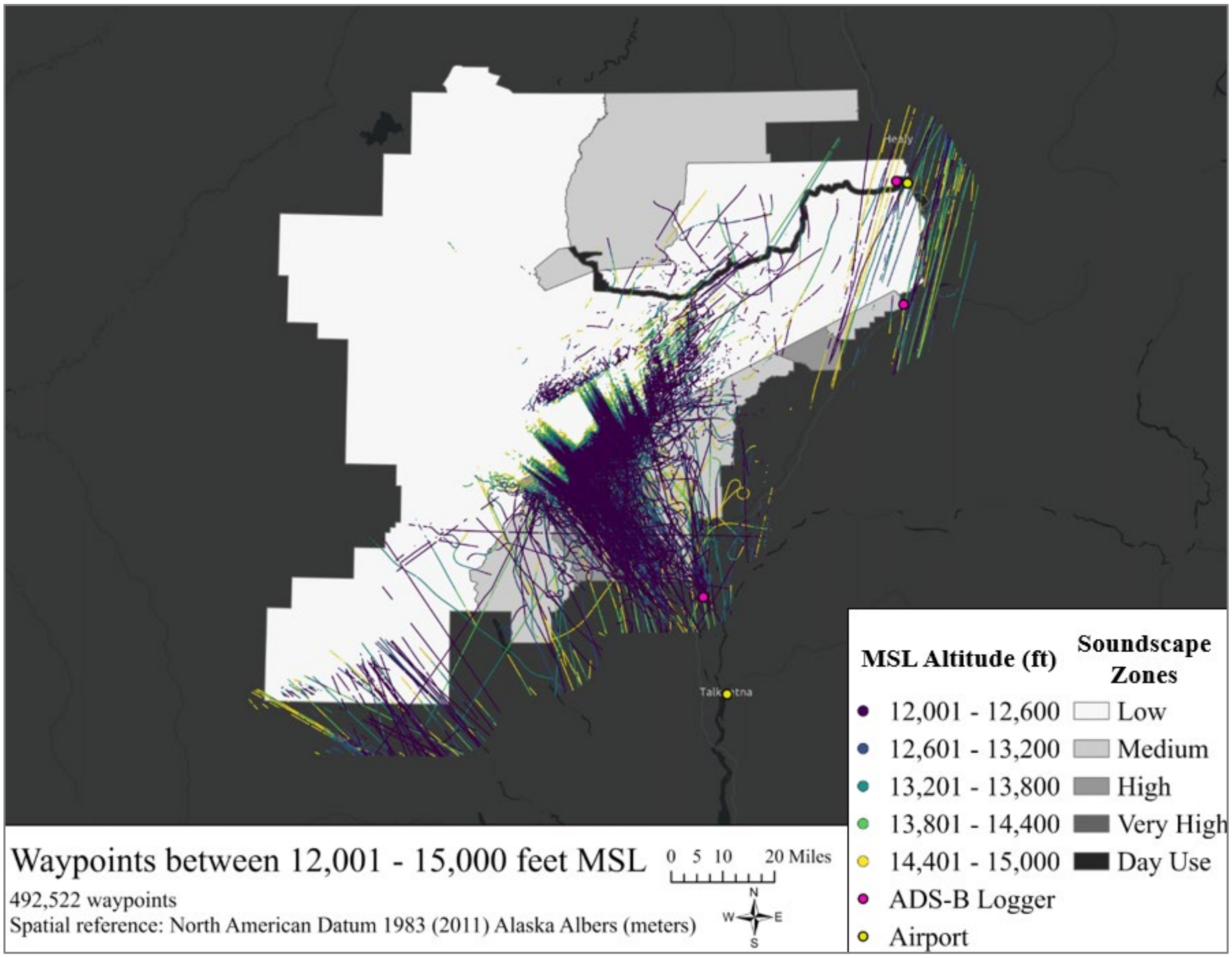

Figure 7. Waypoints between 12,001 and 15,000 feet MSL. NPS / BRIAN PETERSON

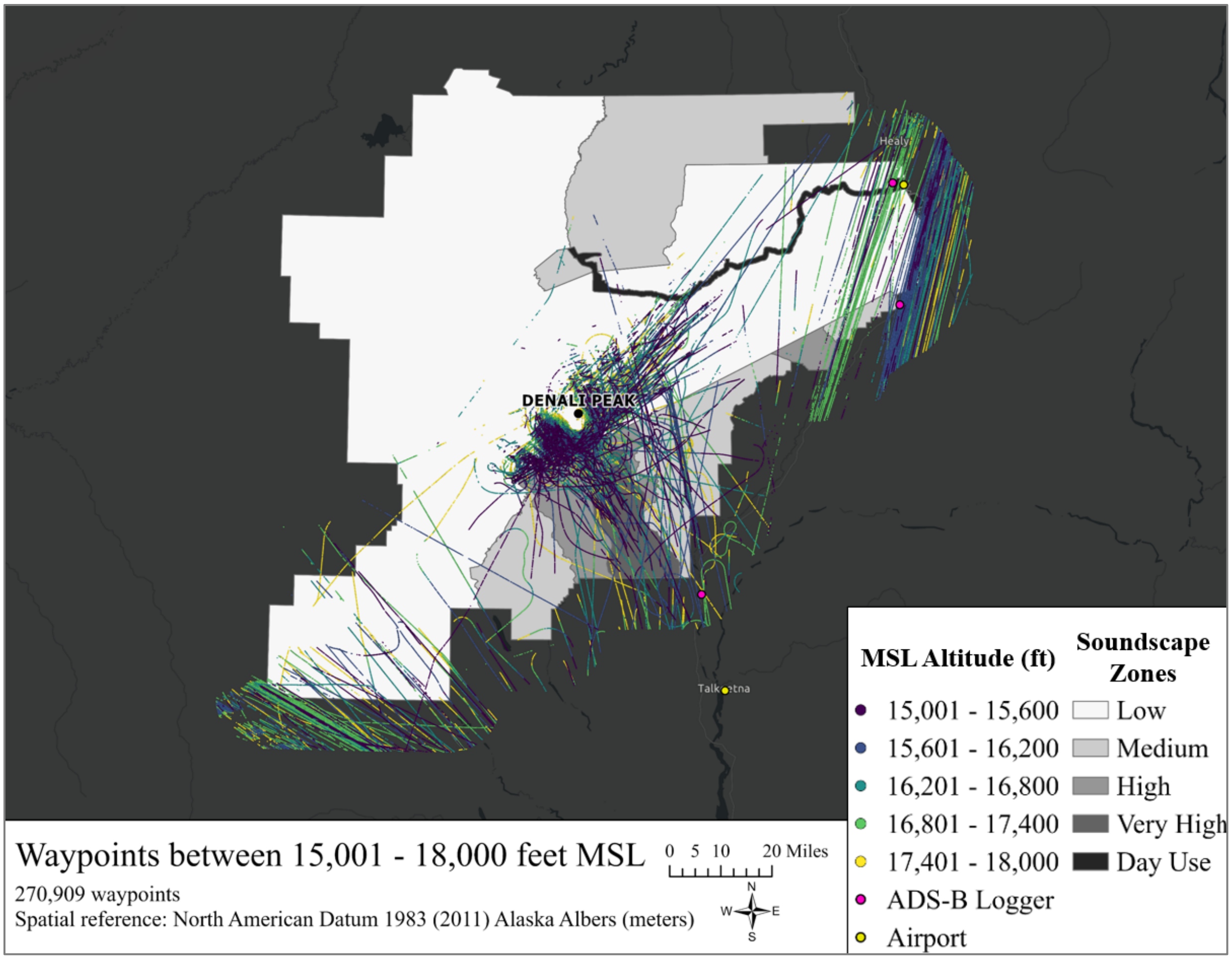

Figure 8. Waypoints between 15,001 and 18,000 feet MSL. NPS / BRIAN PETERSON

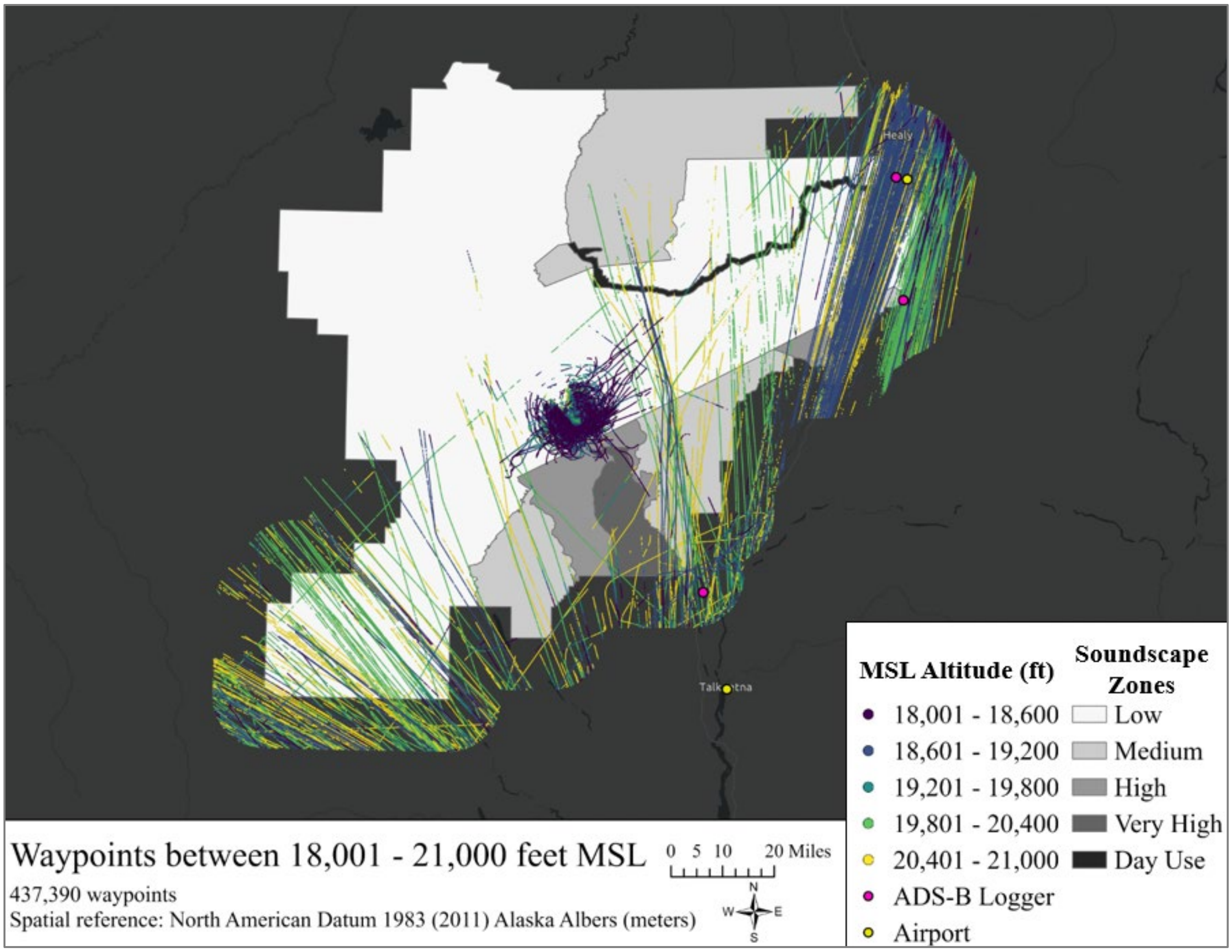

Figure 9. Waypoints between 18,001 and 21,000 feet MSL. NPS / BRIAN PETERSON

Results—Phase 3

Data were cleaned to focus analysis on low-level overflights including air tours, which resulted in the following numbers of flights removed: 587 government flights, 19,184 straight-line flights, 91 flights with a flightpath less than a mile in length, 2 survey flights, and 670 commercial airline flights (note: most of the commercial airline flights were likely removed during the cleaning of straight-line flights). This left 19,154 flights within 10-miles of the DENA boundary (Figure 10). Next, these flights were clipped to a 0.5-mile boundary of DENA, which left 14,307 flights. Using this dataset, kernel density analysis was conducted across AGL altitude intervals up to 4,501–5,000 feet AGL. The altitude interval that showed the most density was 0–500 feet AGL. As described in the Methods, this density altitude was then used as the baseline to normalize the other altitude ranges. However, after normalization, no other altitude intervals showed density hot spots. The 0–500 feet AGL altitude interval shows two density hot spots with a more intense hot spot that results from flights connecting the complex of airports within and adjacent to the DENA frontcountry (Figure 11).

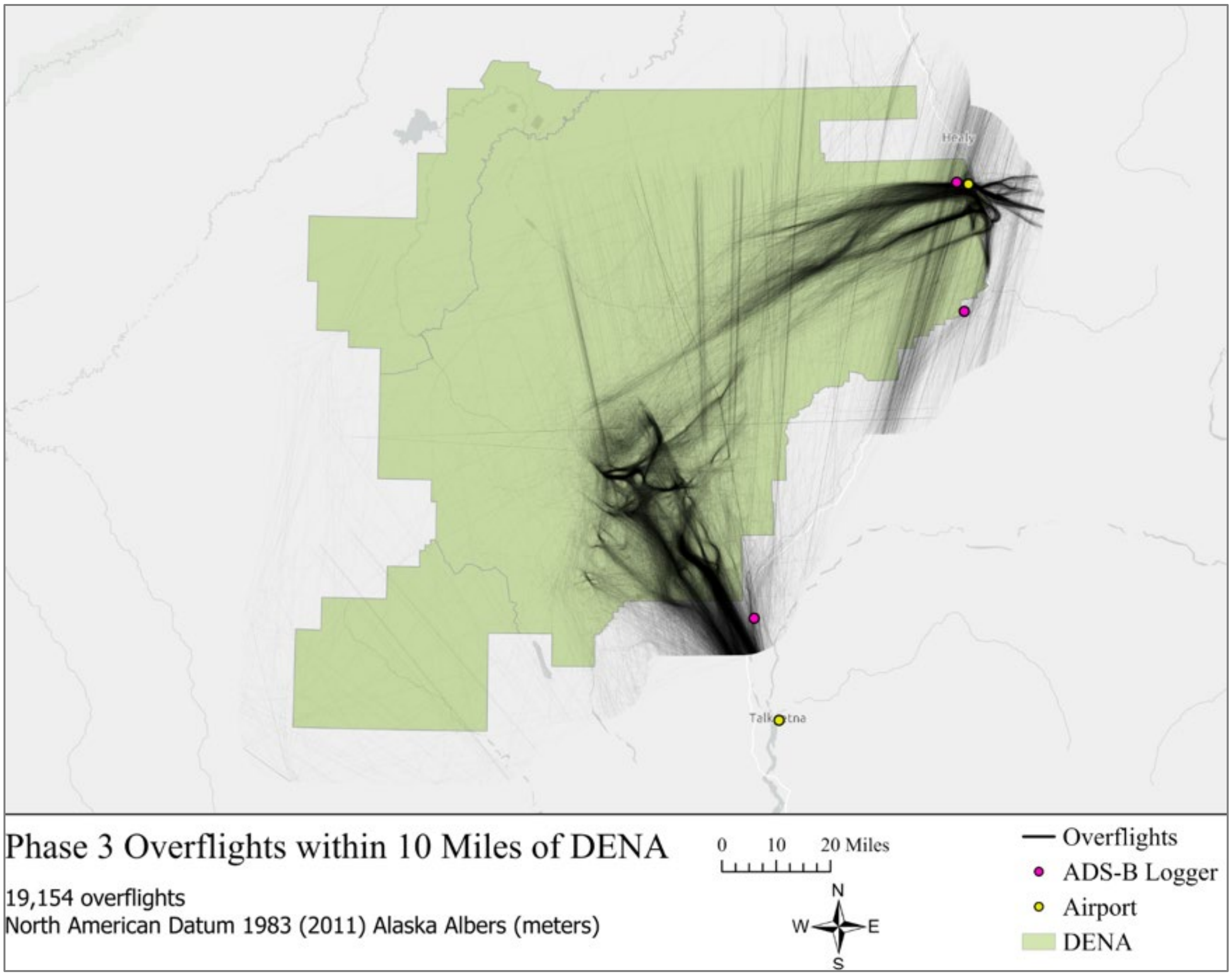

Figure 10. Overview of Phase 3 flights. NPS / BRIAN PETERSON

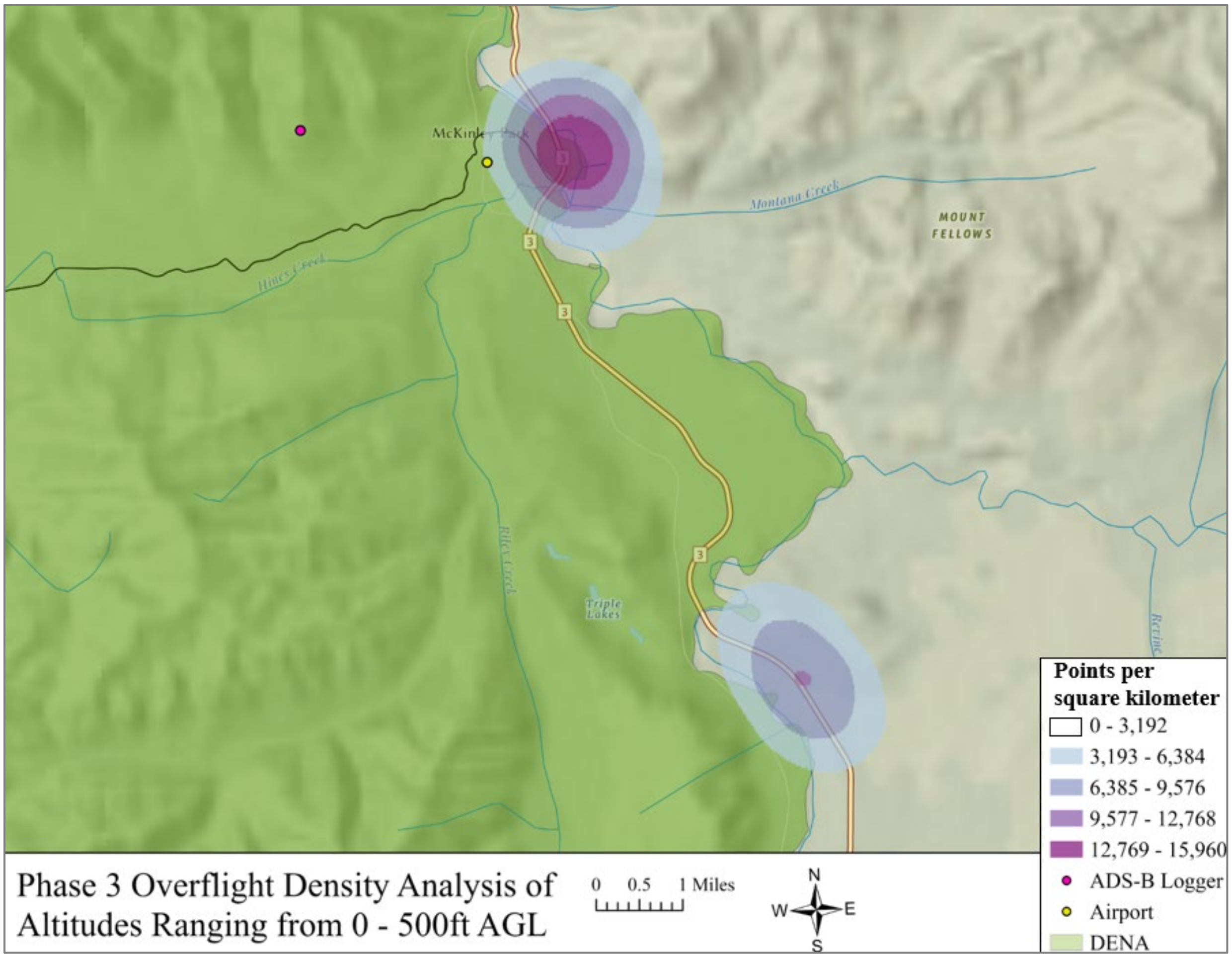

Figure 11. Overview of kernel density analysis showing AGL altitudes ranging from 0 to 500 feet.
NPS / BRIAN PETERSON

To further understand altitude trends of waypoints, seven visualizations were produced that focus on waypoints within 0.5-mile of the DENA boundary. Figure 12 examines altitudes less than 0 feet AGL. Any tracking point with a negative AGL is due to error, although identifying the exact error can be difficult. However, further examination of these data revealed that seven tail numbers accounted for 87.97% of these waypoints. Because many of the data revealed substantial errors, these aircraft likely have an ADS-B system error. More broadly, other error sources could be aircraft flying exceptionally low (including for takeoff and landing operations) combined with DEM generalization errors and errors between barometric altitude estimates and actual altitude.

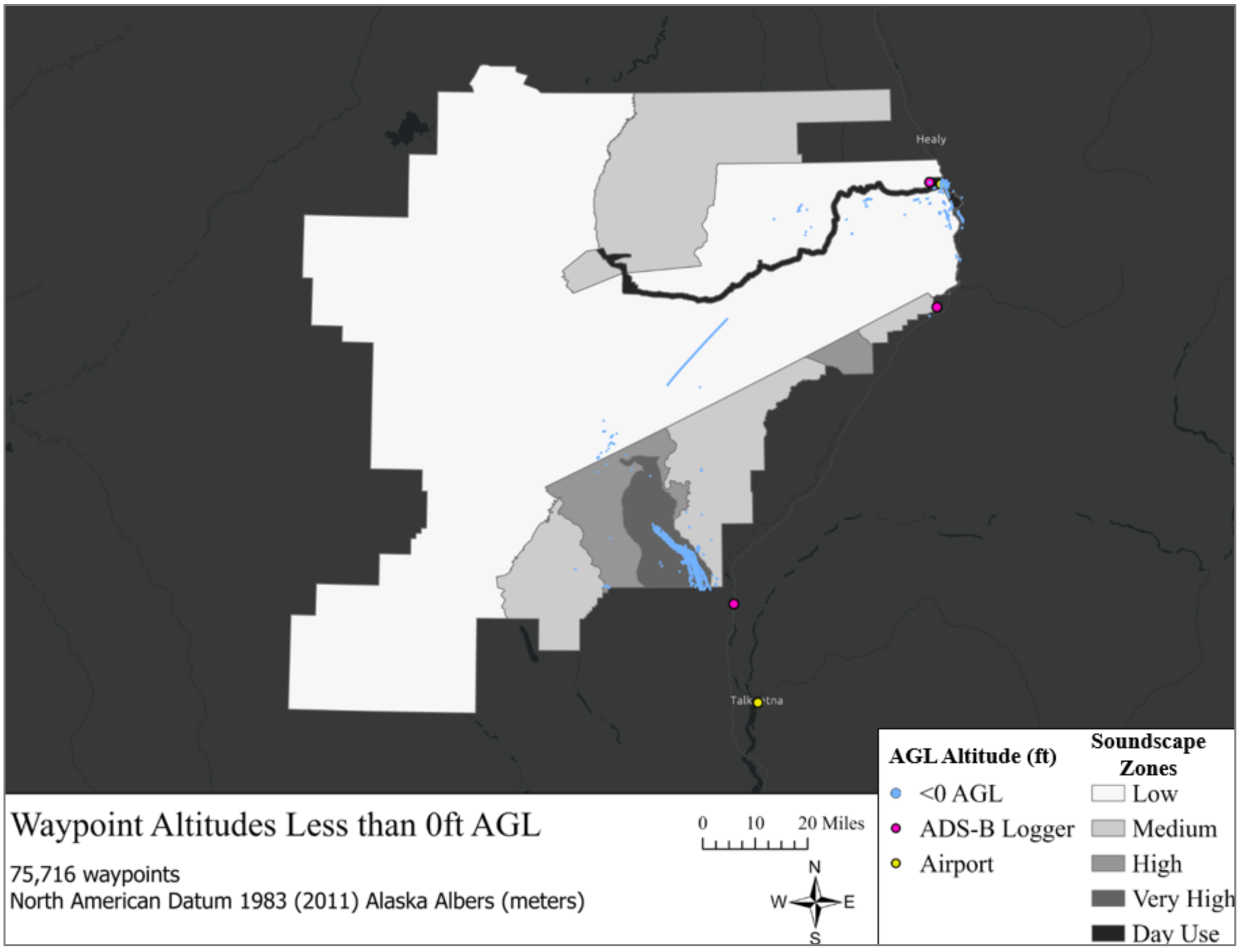

Figure 12. AGL altitude trends of altitudes less than 0 feet AGL for waypoints within 0.5-mile of the DENA boundary (*n*=75,716 waypoints). NPS / BRIAN PETERSON

Figure 13 (altitudes ranging from 0 to 2,500 feet AGL) and Figure 14 (altitudes ranging from 2,501 to 5,000 feet AGL) display AGL altitude trends above the south and east sides of DENA. Figures 15, 16, 17, and 18 display waypoints expressed in MSL. The maximum altitude used was 21,000 feet because Denali's summit is 20,310 feet (National Park Service, 2024). Figure 15 (altitudes ranging from 0 to 5,250 feet MSL), Figure 16 (altitudes ranging from 5,251 to 10,500 feet MSL), Figure 17 (altitudes ranging from 10,501 to 15,750 feet MSL), and Figure 18 (altitudes ranging from 15,751 to 21,000 feet MSL) display MSL altitude trends directly above DENA and show waypoint altitudes trended below 10,500 feet MSL.

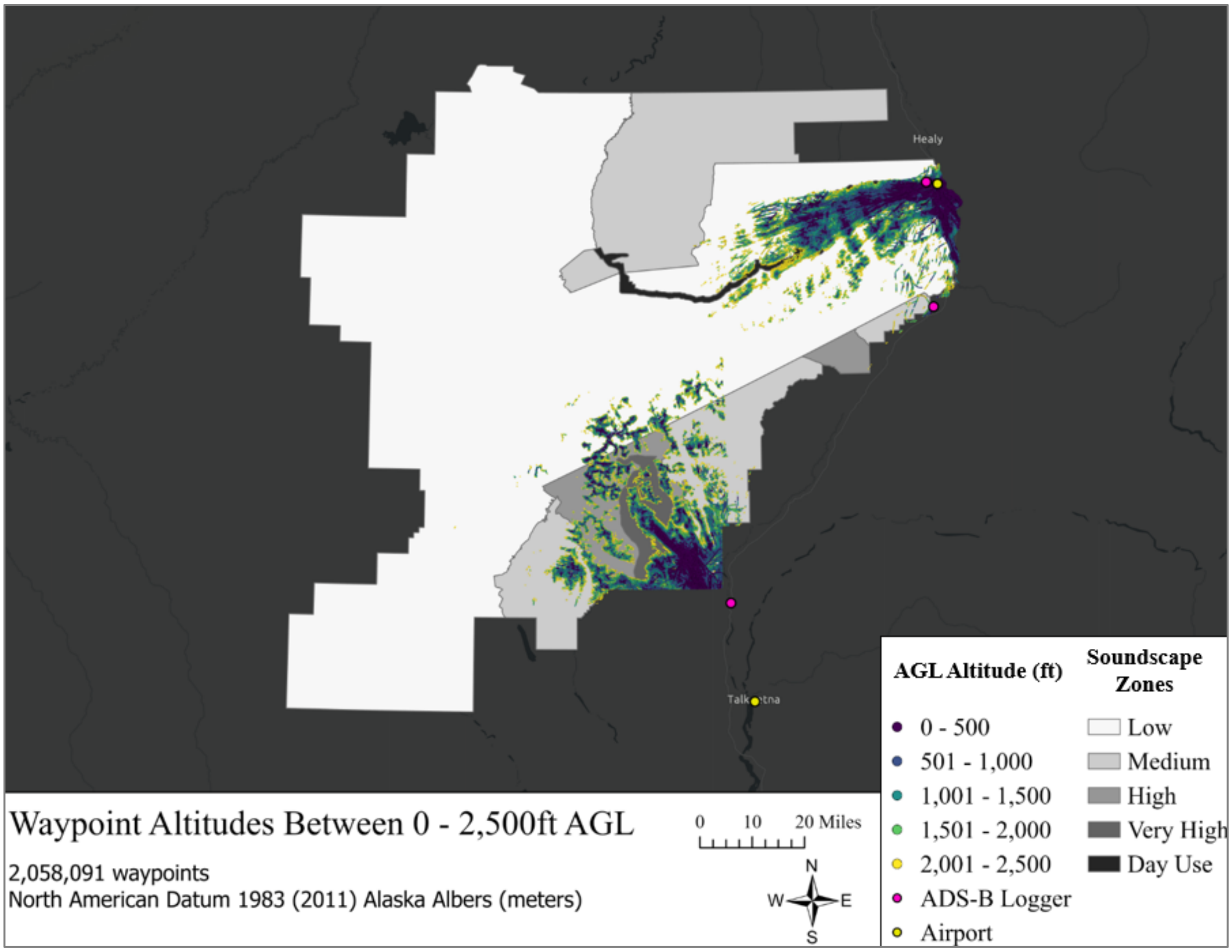

Figure 13. AGL altitude trends of altitudes ranging from 0 to 2,500 feet AGL for waypoints within 0.5-mile of the DENA boundary (*n*=2,058,091 waypoints). NPS / BRIAN PETERSON

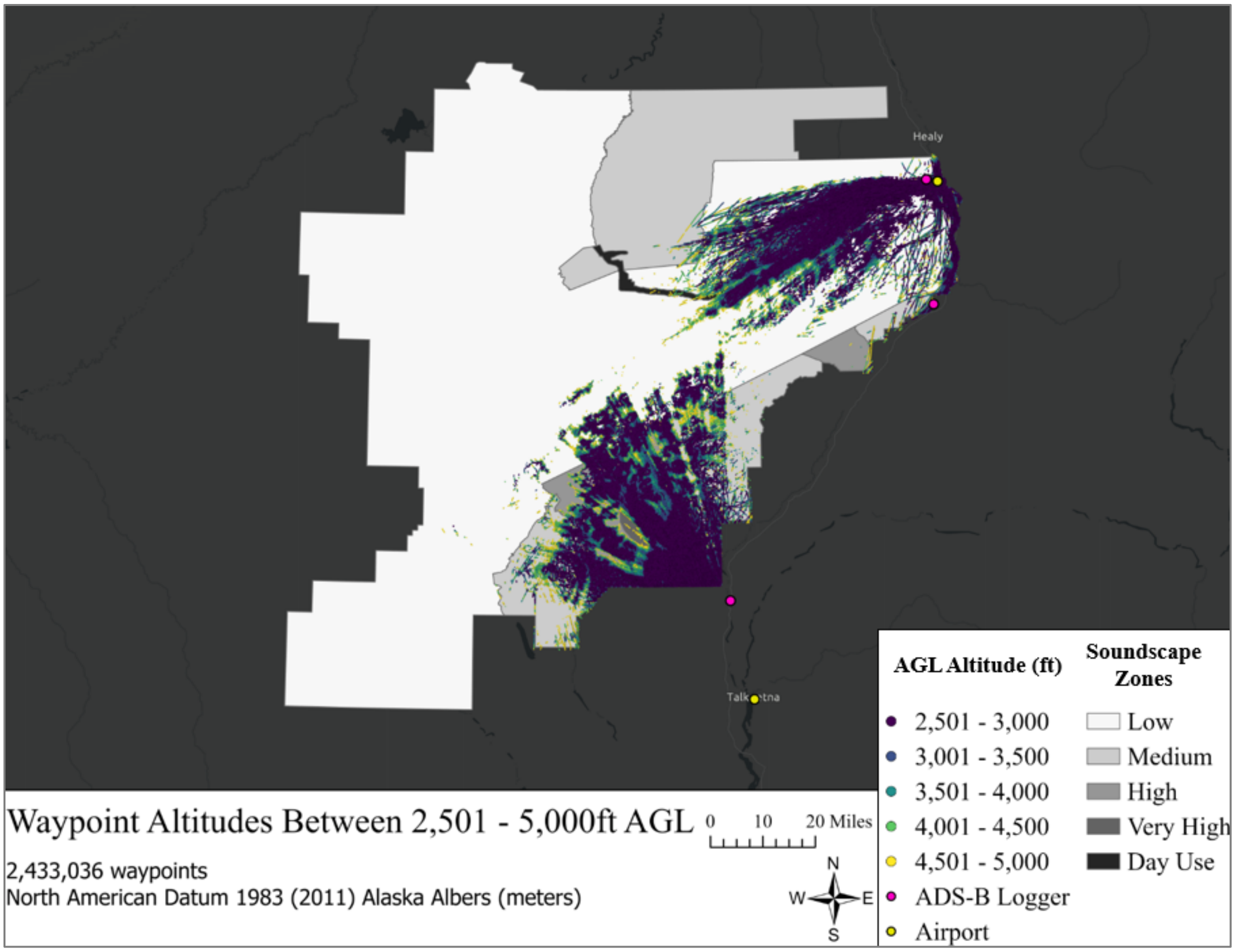

Figure 14. AGL altitude trends of altitudes ranging from 2,501 to 5,000 feet AGL for waypoints within 0.5-mile of the HAVO boundary (*n*=1,494,736 waypoints). NPS / BRIAN PETERSON

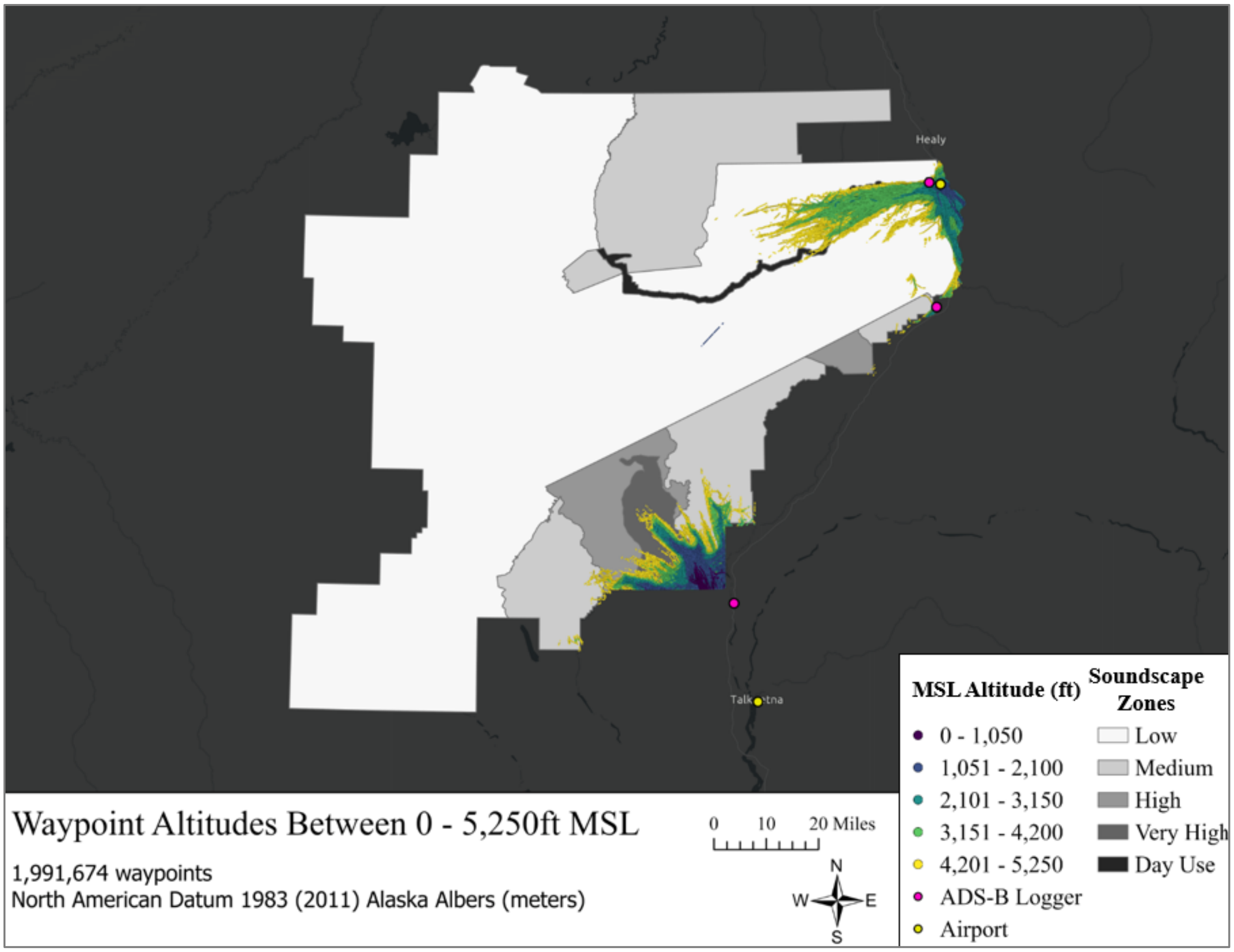

Figure 15. MSL altitude trends of altitudes ranging from 0 to 5,250 feet MSL for waypoints within 0.5-mile of the DENA boundary (*n*=1,991,674 waypoints). NPS / BRIAN PETERSON

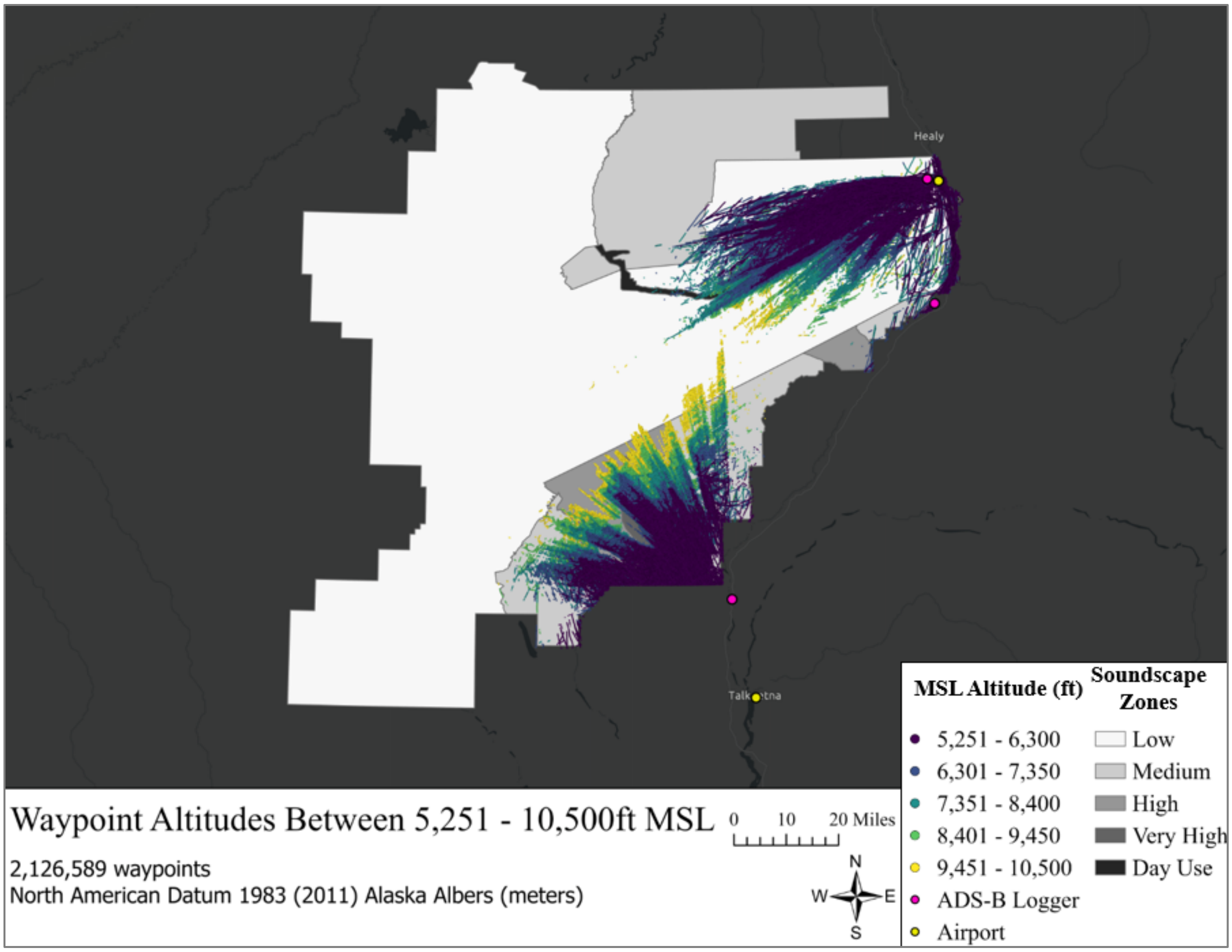

Figure 16. MSL altitude trends of altitudes ranging from 5,251 to 10,500 feet MSL for waypoints within 0.5-mile of the DENA boundary (*n*=2,126,589 waypoints). NPS / BRIAN PETERSON

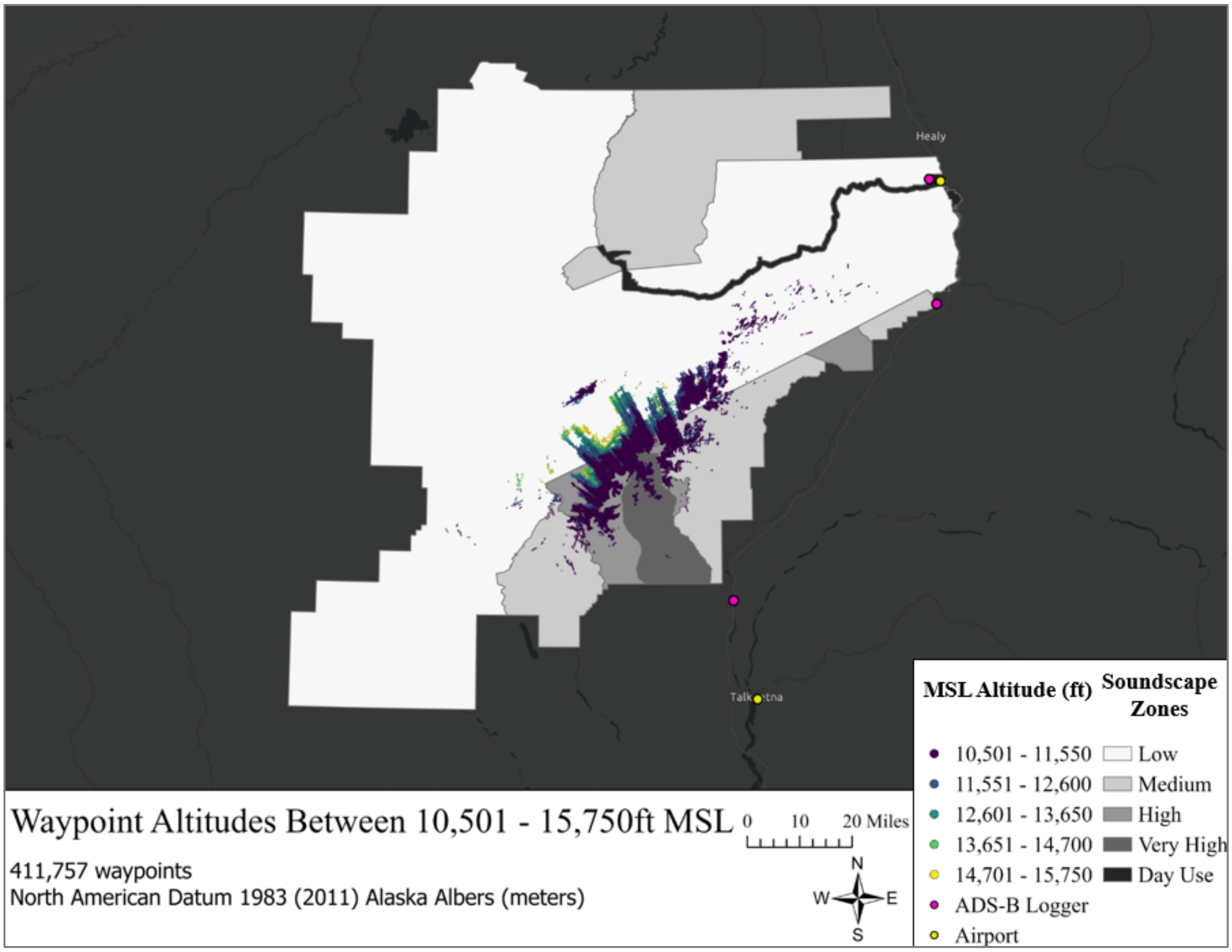

Figure 17. MSL altitude trends of altitudes ranging from 10,501 to 15,750 feet MSL for waypoints within 0.5-mile of the DENA boundary (*n*=411,757 waypoints). NPS / BRIAN PETERSON

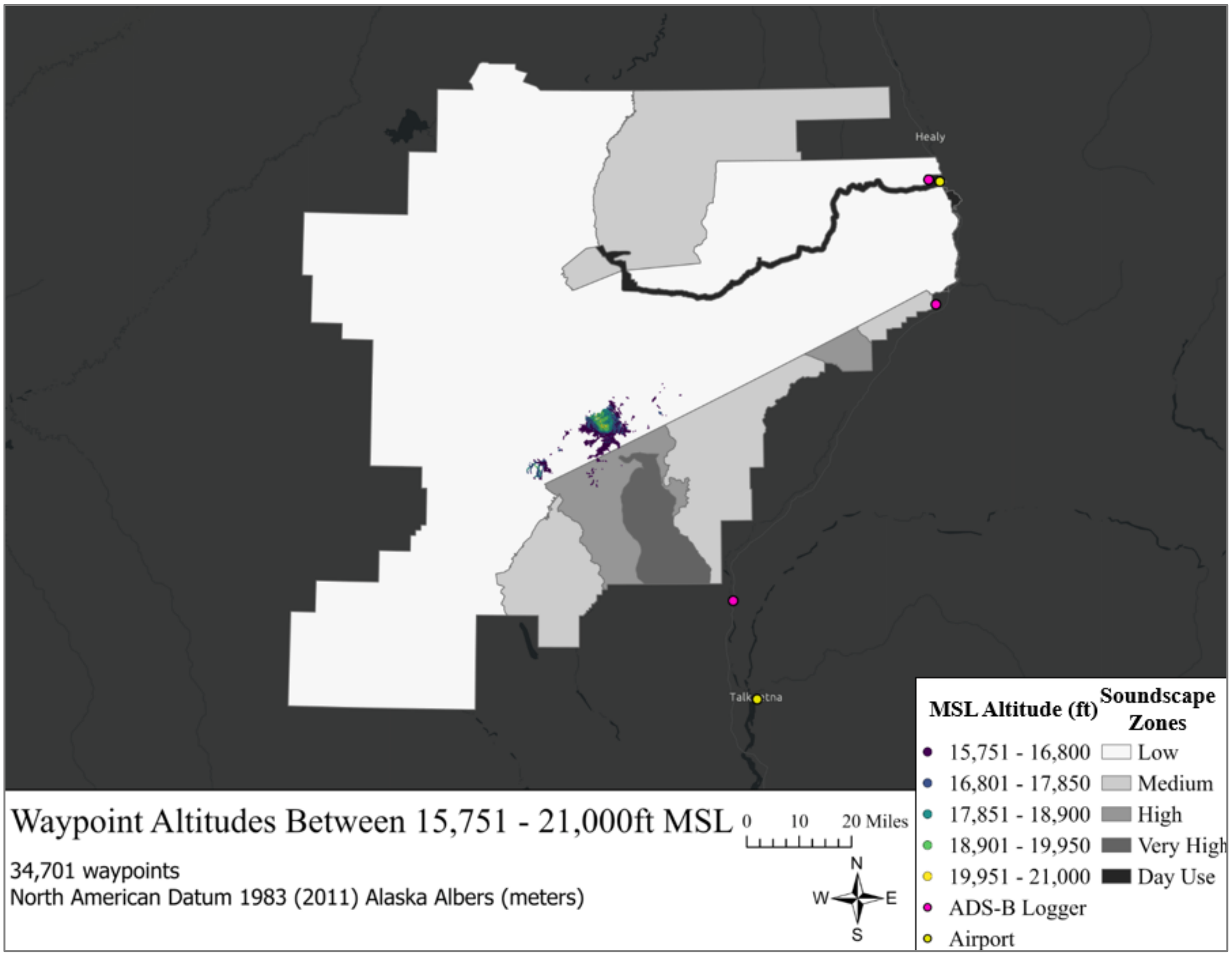

Figure 18. MSL altitude trends of altitudes ranging from 15,751 to 21,000 feet MSL for waypoints within 0.5-mile of the DENA boundary (*n*=34,701 waypoints). NPS / BRIAN PETERSON

The information displayed in Figures 12–18 was inputted into tables to quantitatively understand which altitude intervals had the highest percentage of observed waypoints. Table 2 shows analysis of 4,565,876 waypoints across AGL altitudes and Table 3 shows analysis of 6,111,452 waypoints across MSL altitudes. The AGL altitude interval that received the highest percentage of waypoints was 3,001–3,500 feet (Table 2), but note that the following altitude intervals had a significant number of waypoints: 1,001–1,500 feet AGL; 1,501–2,000 feet AGL; 2,001–2,500 feet AGL; 2,501–3,000 feet AGL; 3,501–4,000 feet AGL; and 4,001–4,500 feet AGL. The MSL altitude interval that received the high percentage of waypoints was 6,001–7,000 feet (Table 3), but note that the following altitude intervals had a significant number of waypoints: 5,001–6,000 feet MSL; 7,001–8,000 feet MSL; and 8,001–9,000 feet MSL.

Table 2. Number and percentage of waypoints across AGL altitude intervals (*n*=4,565,876).

AGL altitude	Number of waypoints	Percentage of waypoints
< 0ft	75,716 [A]	1.7
0–500ft	234,672	5.1
501–1,000ft	386,334	8.5
1,001–1,500ft	466,295	10.2
1,501–2,000ft	474,123	10.4
2,001–2,500ft	496,667	10.9
2,501–3,000ft	516,284	11.3
3,001–3,500ft	520,780	11.4
3,501–4,000ft	518,101	11.3
4,001–4,500ft	474,683	10.4
4,501–5,000ft	402,221	8.8

[A] 87.97% of these data were accounted for by seven aircraft.

Table 3. Number and percentage of waypoints across MSL altitude intervals (*n*=6,111,452).

MSL altitude	Number of waypoints	Percentage of waypoints
0–1,000ft	3,497	0.1
1,001–2,000ft	234,996	3.8
2,001–3,000ft	497,793	8.1
3,001–4,000ft	576,540	9.4
4,001–5,000ft	543,410	8.9
5,001–6,000ft	618,525	10.1
6,001–7,000ft	660,670	10.8
7,001–8,000ft	646,405	10.6
8,001–9,000ft	615,522	10.1
9,001–10,000ft	459,441	7.5
10,001–11,000ft	367,591	6
11,001–12,000ft	344,626	5.6
12,001–13,000ft	190,021	3.1
13,001–14,000ft	66,403	1.1
14,001–15,000ft	37,131	0.6
15,001–16,000ft	34,088	0.6
16,001–17,000ft	34,165	0.6
17,001–18,000ft	36,626	0.6
18,001–19,000ft	56,063	0.9
19,001–20,000ft	34,622	0.6

Table 3 (continued). Number and percentage of waypoints across MSL altitude intervals (*n*=6,111,452).

MSL altitude	Number of waypoints	Percentage of waypoints
20,001–21,000ft	53,317	0.9

Next, overflights were analyzed across months, days of the week, and hours of the day (total flights analyzed = 14,307). Table 4 shows number of days low-level overflight data were collected, overflights per month, and average number of flights per day for the data collection duration, which occurred from September 18th, 2021 to October 6th, 2022 and from May 25th, 2023 to September 13th, 2023. DENA received the most overflights during July of 2023 (131.23 average number of flights per day).

Table 4. Number and percentage of overflights across months (*n*=14,307).

Month	Number of data collection days [A]	Number of overflights	Average Number of overflights per day
September 2021	13	25	1.92
October 2021	31	12	0.39
November 2021	30	12	0.40
December 2021	31	3	0.10
January 2022	31	3	0.10
February 2022	28	8	0.29
March 2022	31	18	0.58
April 2022	30	29	0.97
May 2022	31	818	26.39
June 2022	16	1,101	68.81
July 2022	24	1,037	43.21
August 2022	10	450	45.00
September 2022	16	141	8.81
October 2022	6	32	5.33
May 2023 [B]	7	139	19.86
June 2023	30	2,100	70.00
July 2023	31	4,068	131.23
August 2023	31	3,376	108.90
September 2023	13	935	71.92
Total	**440**	**14,307**	**31.80**

[A] For some months, data collection did not occur at all or every day.

[B] Data collection did not occur between October 6th, 2022 and May 25th, 2023.

Table 5 shows the percentage of flights across days of the week. The day of the week with the highest percentage of flights was Wednesdays (15.60%). Table 6 shows the percentage of overflights across hour of the day. Most overflights occur from 11:00am to 3:00pm and from 4:00pm to 5:00pm. Table 7 shows percentage of overflights across aircraft type. Fixed-wing single engine is the aircraft type most common among low-level overflights at DENA.

Table 5. Percentage of overflights across days of the week.

Day of the week	Percent of overflights
Monday	13.7
Tuesday	13.9
Wednesday	15.6
Thursday	14.3
Friday	14.7
Saturday	15.0
Sunday	13.0

Table 6. Percentage of overflights across hours of the day.

Hour	Percentage of overflights
7:00am–8:00am	0.1
8:00am–9:00am	3.4
9:00am–10:00am	6.0
10:00am–11:00am	6.6
11:00am–12:00pm	9.3
12:00pm–1:00pm	9.2
1:00pm–2:00pm	8.0
2:00pm–3:00pm	10.1
3:00pm–4:00pm	6.6
4:00pm–5:00pm	12.1
5:00pm–6:00pm	7.9
6:00pm–7:00pm	6.7
7:00pm-8:00pm	7.1
8:00pm-9:00pm	5.4
9:00pm–10:00pm	1.2
10:00pm-11:00pm	0.1

Table 7. Percentage of overflights across aircraft type.

Aircraft type	Percentage
Fixed-wing single engine	67.8
Fixed-wing multi engine	18.4
Rotorcraft	13.8

Using the cleaned Phase 3 dataset, three more figures were produced to show overflight travel patterns across aircraft type. Figure 19 displays overflight travel patterns for fixed-wing single engine. Figure 20 displays overflight travel patterns for fixed-wing multi engine aircraft. Figure 21 displays overflight travel patterns for rotorcraft aircraft.

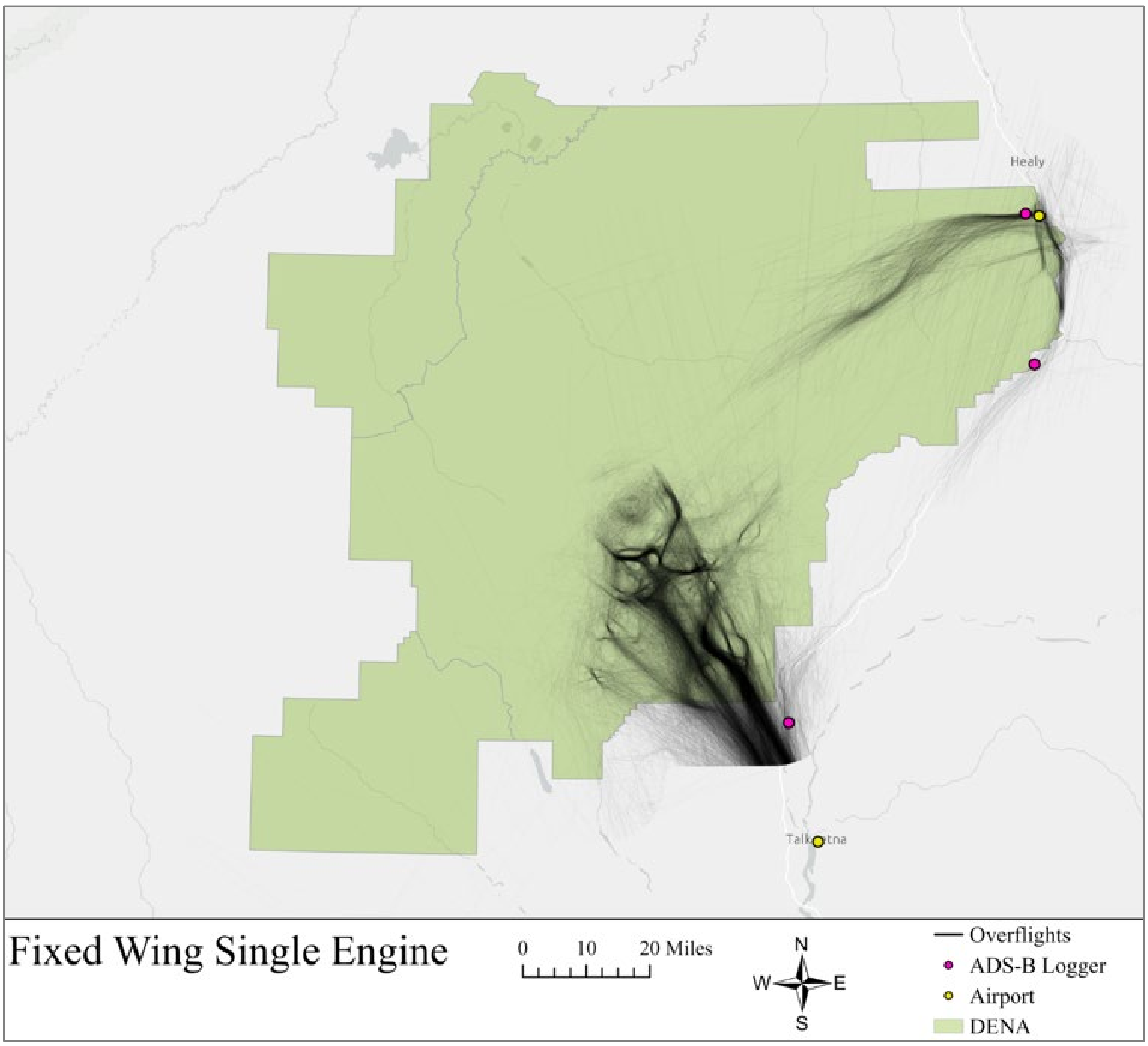

Figure 19. Phase 3 fixed-wing single engine overflight travel patterns. NPS / BRIAN PETERSON

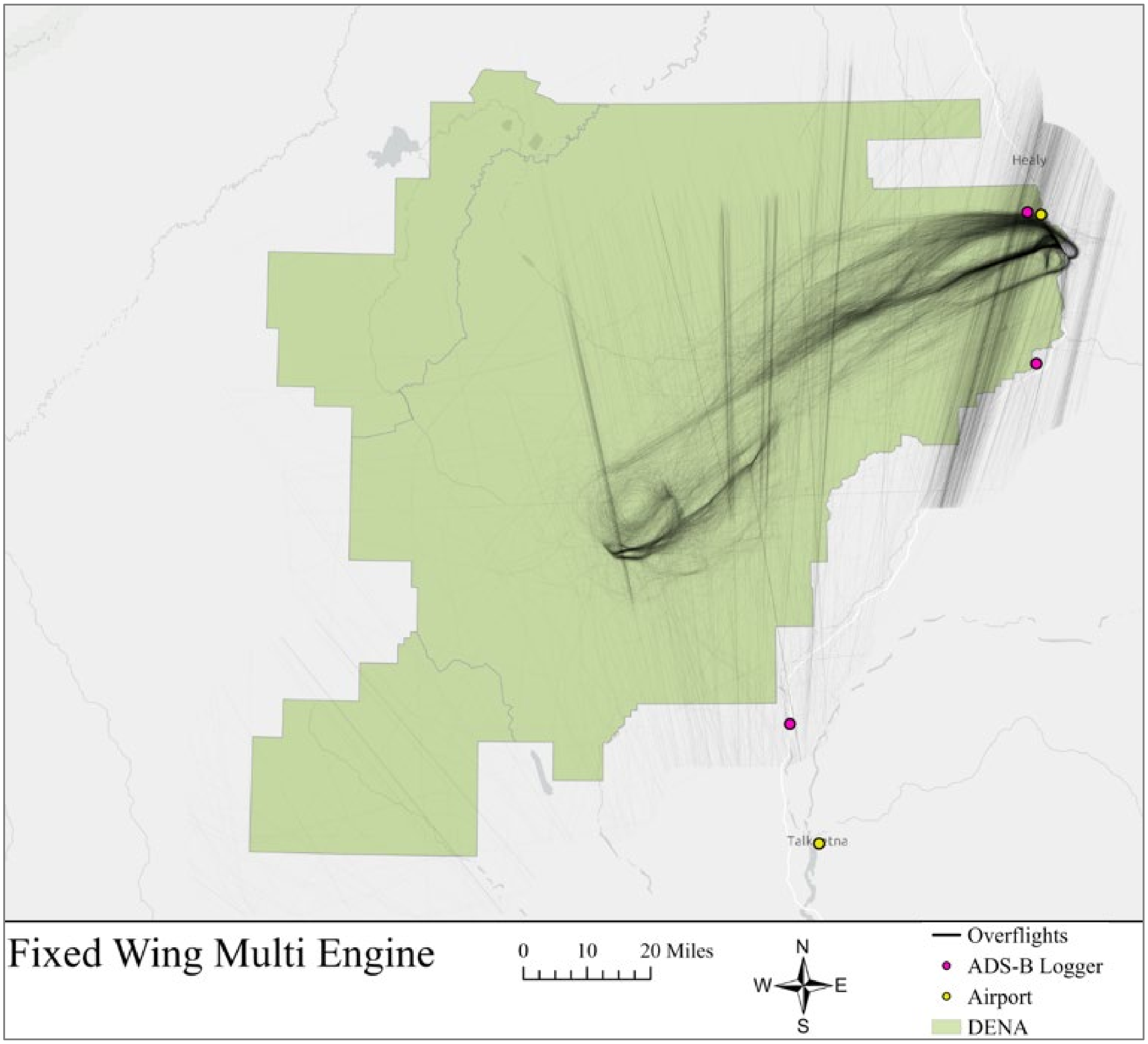

Figure 20. Phase 3 fixed-wing multi engine overflight travel patterns. NPS / BRIAN PETERSON

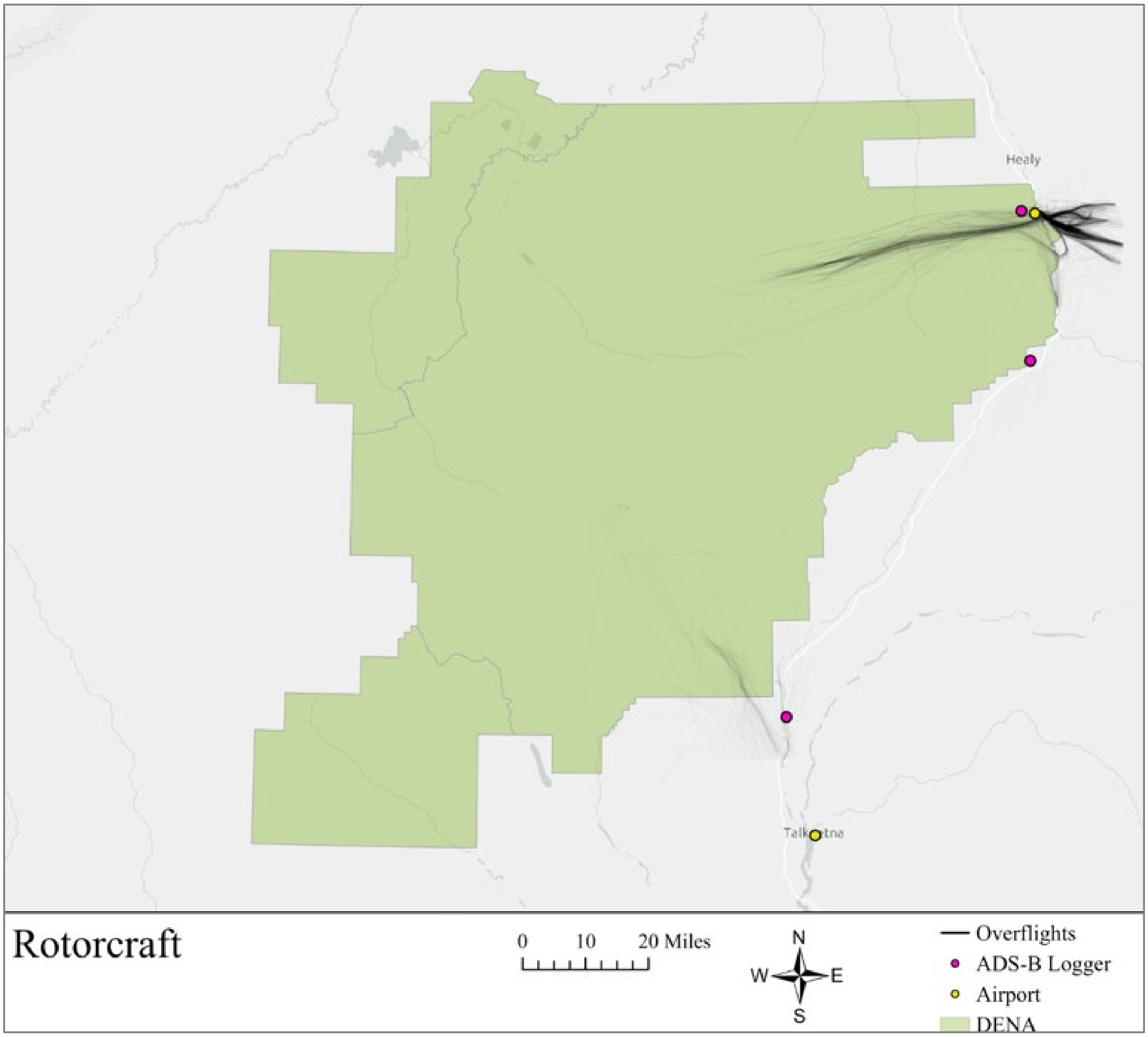

Figure 21. Phase 3 rotorcraft overflight travel patterns. NPS / BRIAN PETERSON

Lastly, analysis was conducted for tail numbers that DENA managers identified as aircraft that are used to help in the administration of the park, such as mountaineering helicopters. These aircrafts' travel patterns are mapped in Figure 22 and include tail numbers: N21HY, N709M, N437CC, N473YC, N192CC, N706M, N534L, N278CC, N1004, N9871D, N570AE, N970TH, N644TC, N567L, N446TC, and N149AE. Next, the two aircraft that conducted the most administrative flights were mapped. Figure 23 displays flightpaths for tail number N570AE (273 overflights). Figure 24 displays flightpaths for tail number N149AE (93 overflights). Figure 25 displays fixed-wing single engine administrative overflight travel patterns. Figures 26, 27, and 28 show Phase 3 data overlaid on sound sensitive areas which the Denali Aircraft Overflights Advisory Council agreed worthy of enhancing quiet (National Park Service, 2018b).

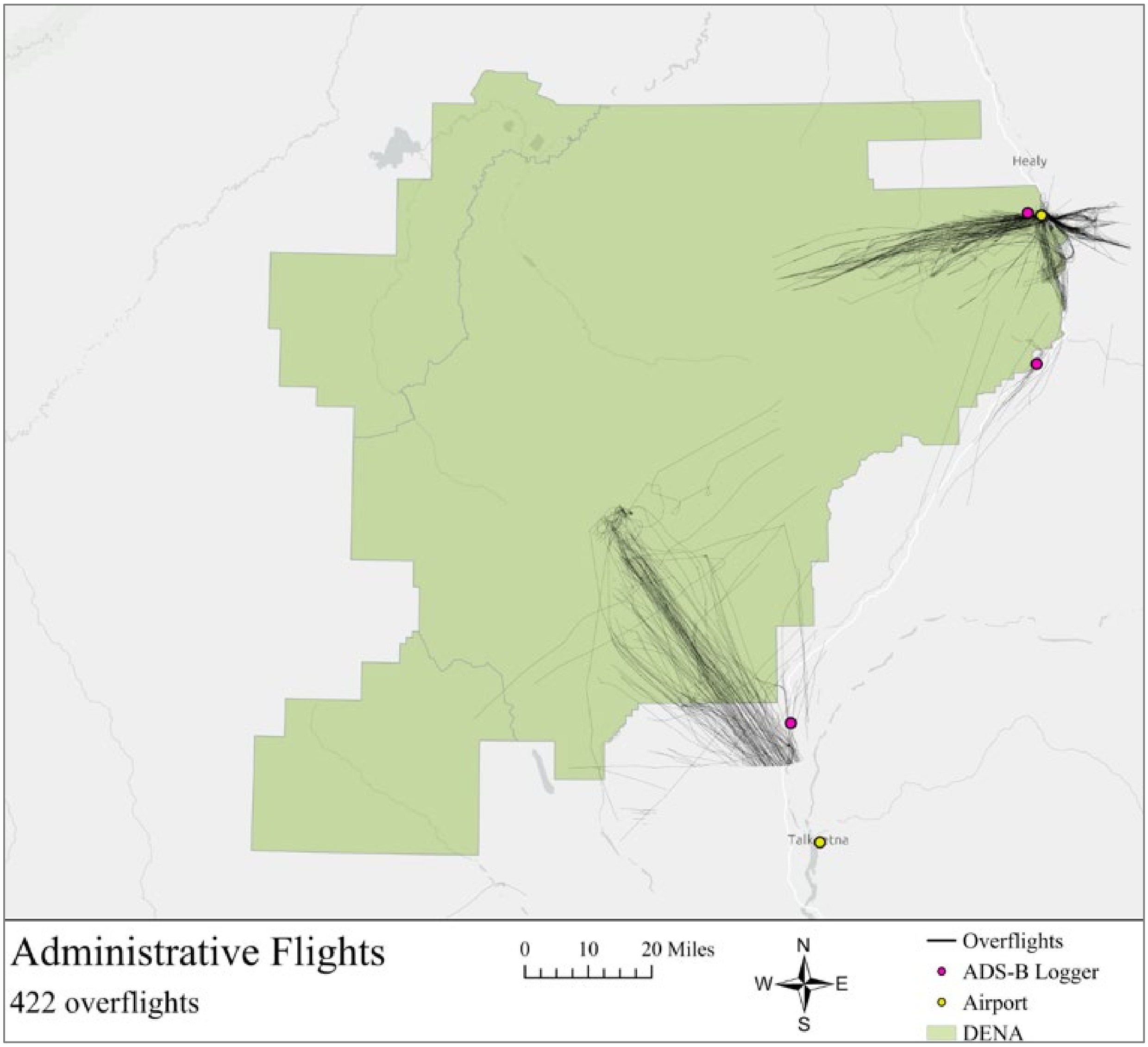

Figure 22. Administrative overflight travel patterns. NPS / BRIAN PETERSON

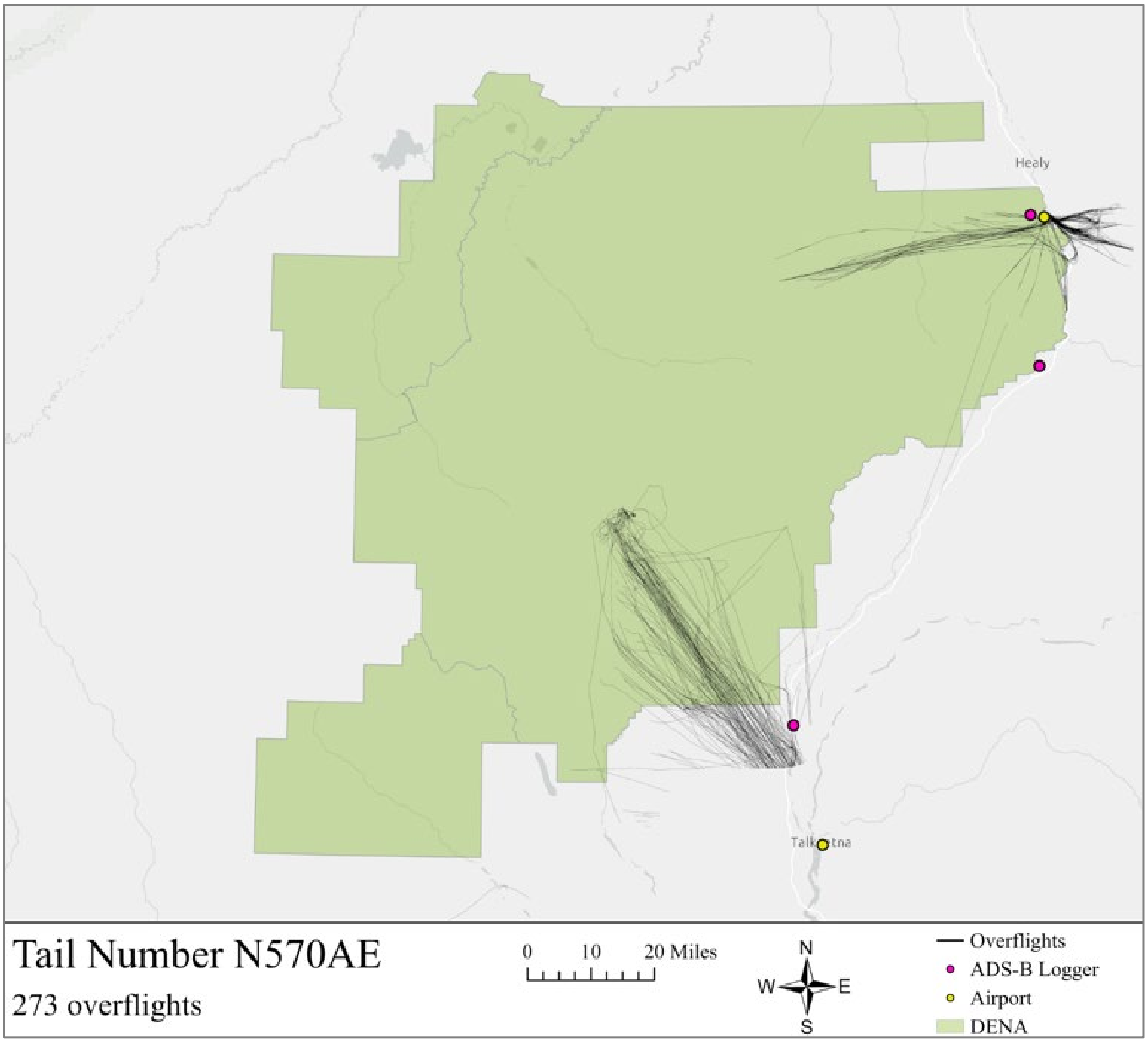

Figure 23. Tail number N570AE overflight travel patterns. NPS / BRIAN PETERSON

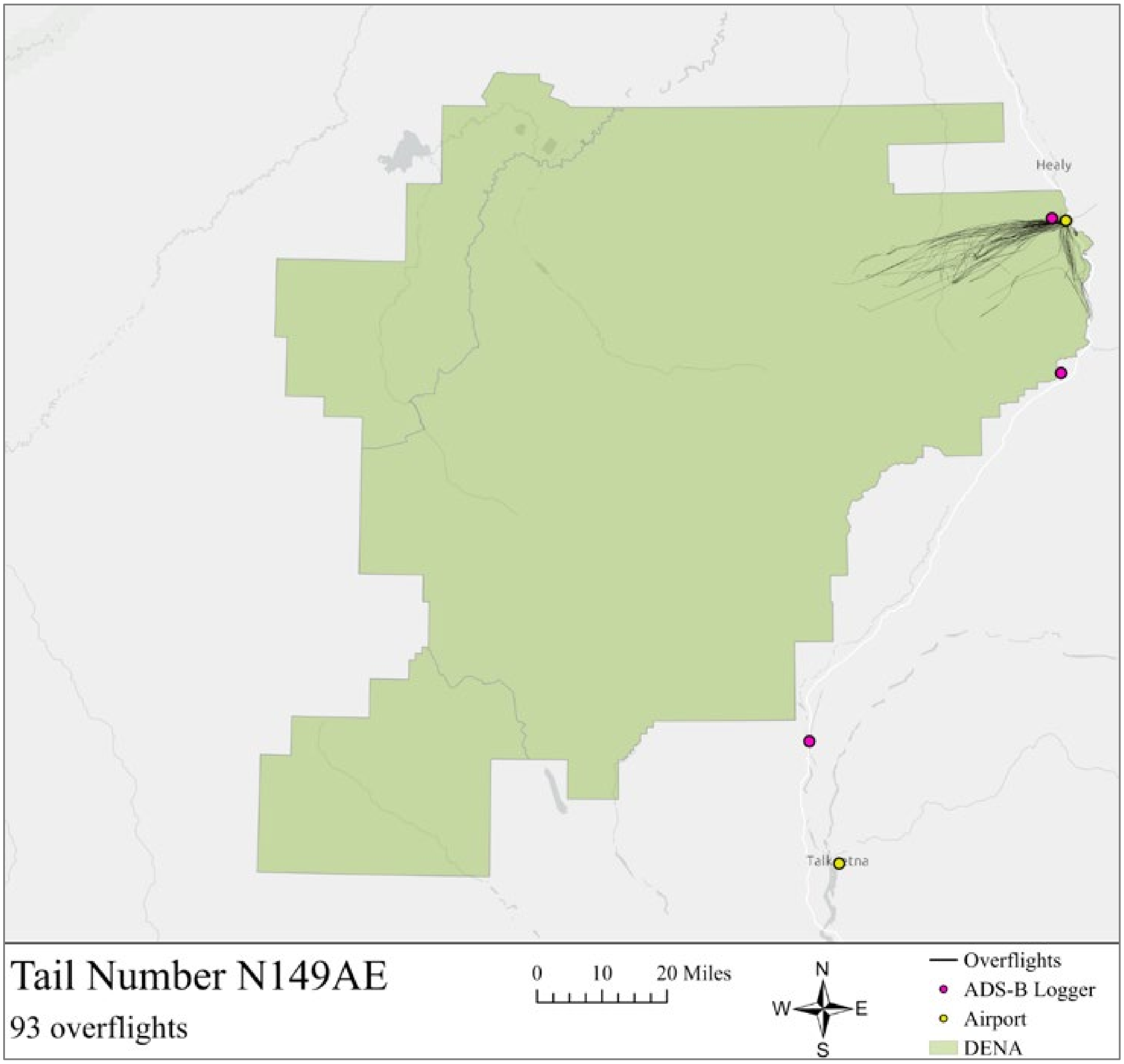

Figure 24. Tail number N149AE overflight travel patterns. NPS / BRIAN PETERSON

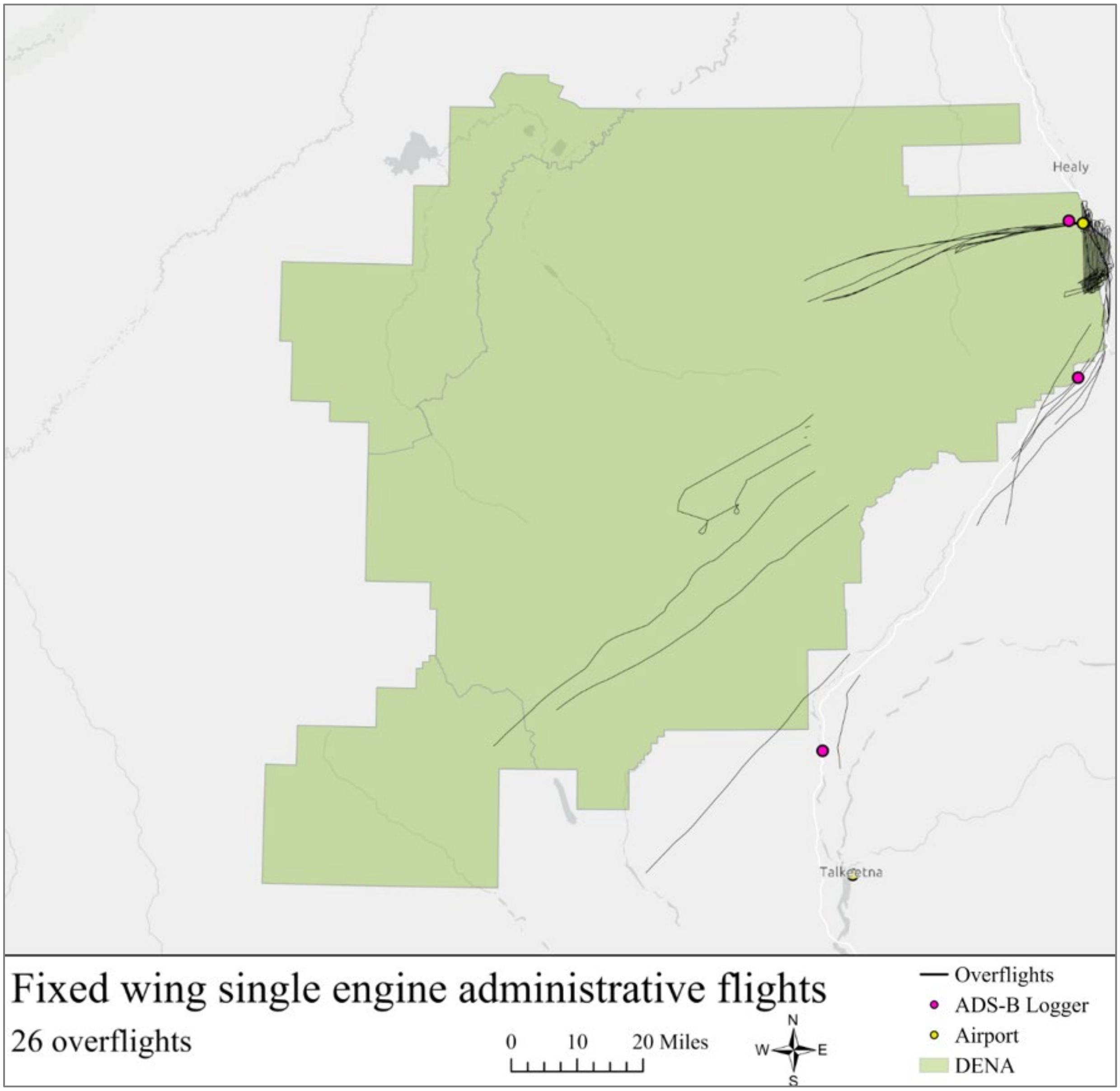

Figure 25. Fixed-wing single engine administrative overflight travel patterns. NPS / BRIAN PETERSON

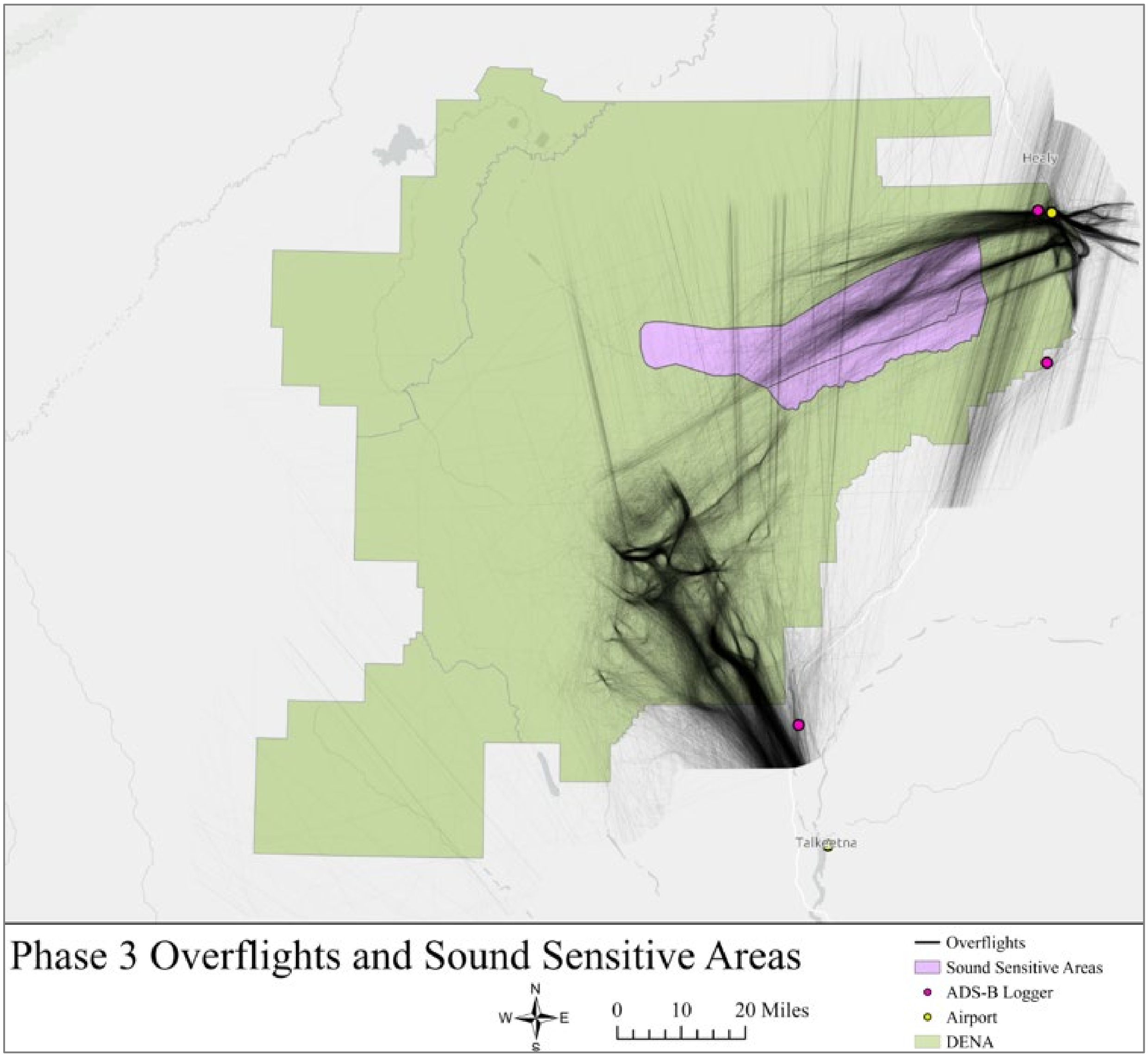

Figure 26. Phase 3 overflights and sound sensitive areas. NPS / BRIAN PETERSON

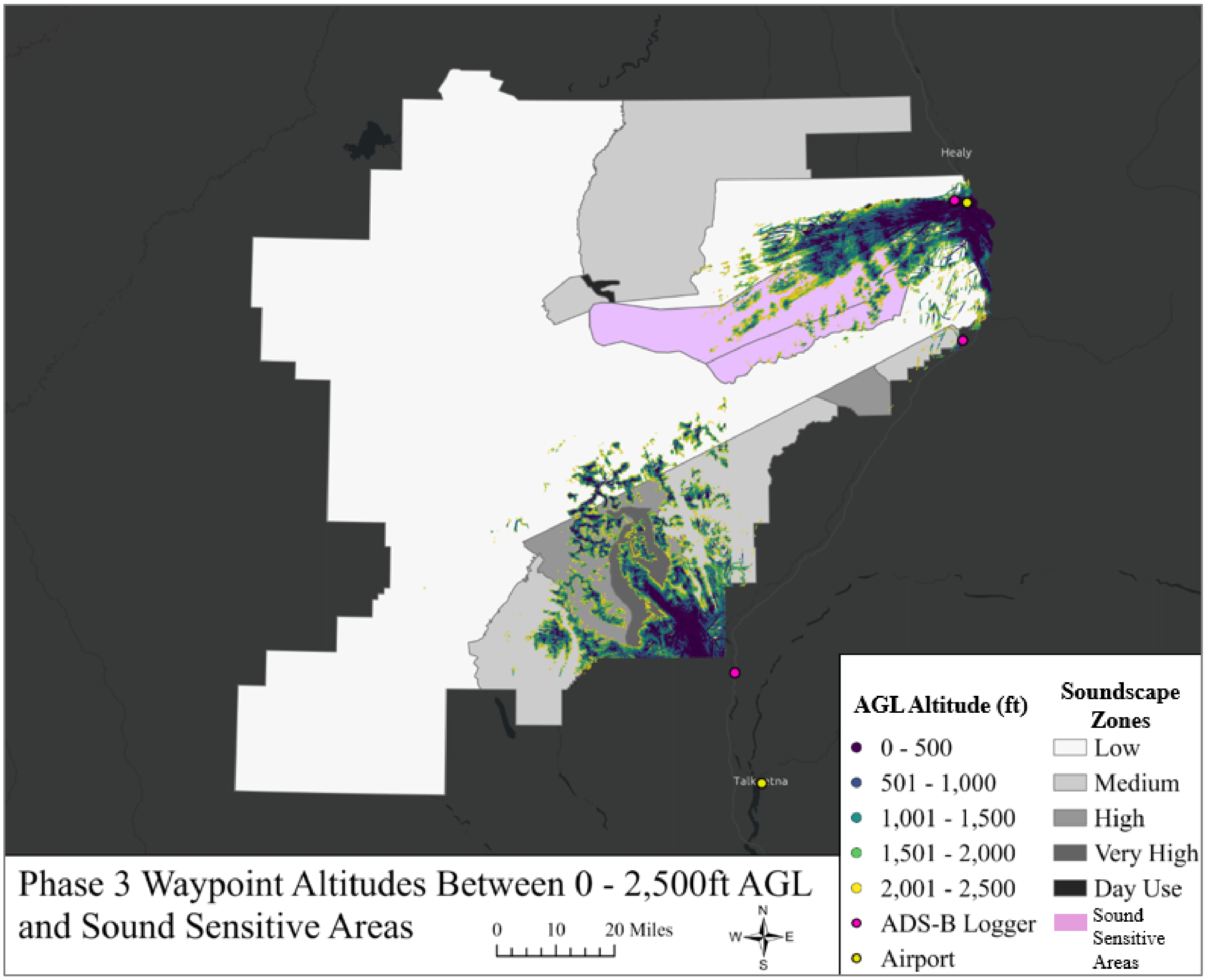

Figure 27. AGL altitude trends of altitudes ranging from 0 to 2,500 feet AGL for waypoints within 0.5-mile of the DENA boundary and sound sensitive areas. NPS / BRIAN PETERSON

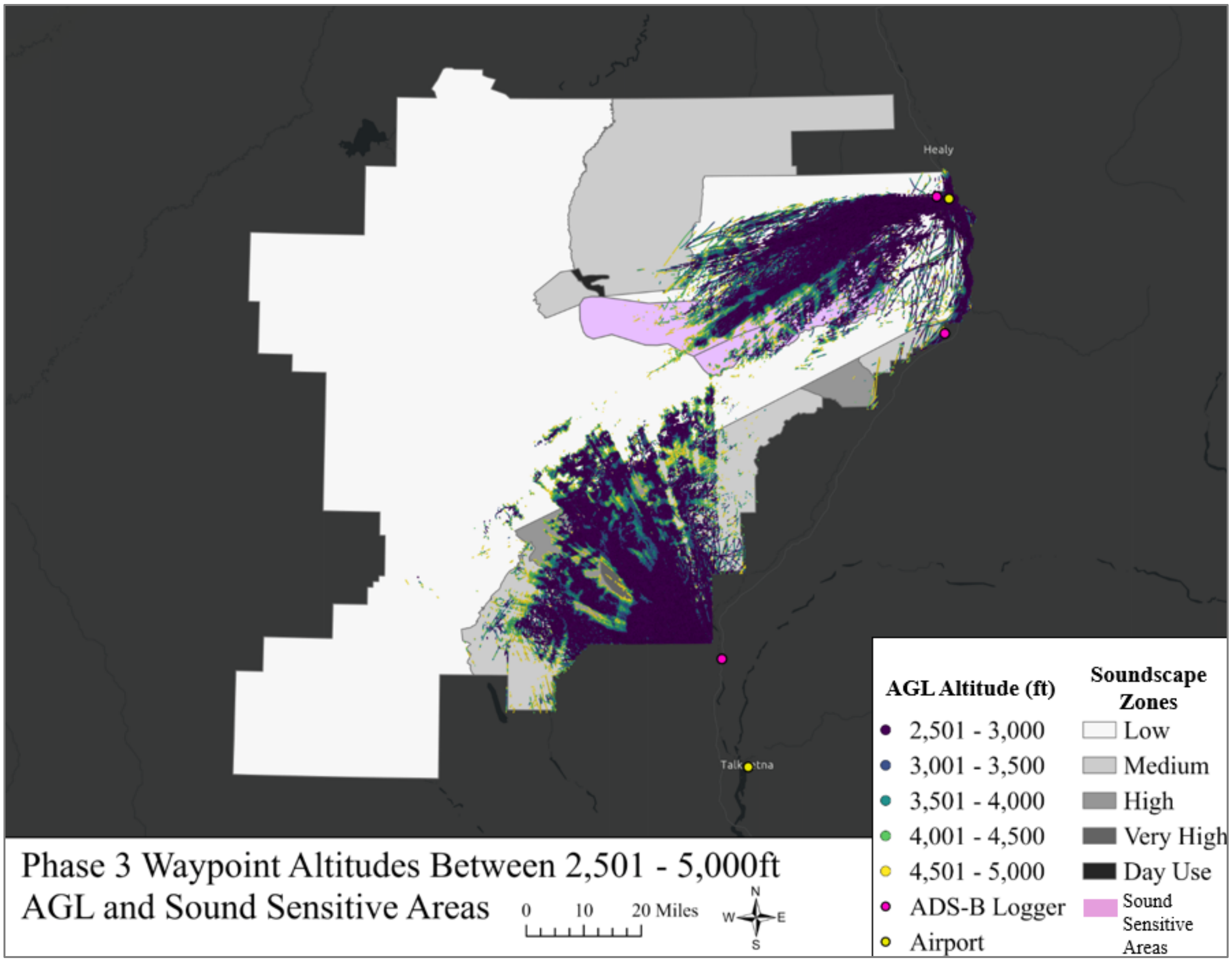

Figure 28. AGL altitude trends of altitudes ranging from 2,501 to 5,000 feet AGL for waypoints within 0.5-mile of the DENA boundary and sound sensitive areas. NPS / BRIAN PETERSON

Discussion

The purpose of this study was to explore the spatial and temporal patterns of overflights at DENA. Three ADS-B units were deployed along the eastern boundary of DENA. Flight tracking data were analyzed from September 18th, 2021 to October 6th, 2022 (384 total days; 56 days of missing data) and from May 25th, 2023 to September 13th, 2023 (112 total days; 0 days of missing data). Analysis consisted of three phases.

The first phase focused on all overflights. Observations showed a concentrated trend of overflights above the east and south sides of DENA. In the east, the Denali National Park Airport receives concentrated overflights. In the south, glacier paths in the Alaska Range are popular for aircraft to follow. Further, flights that approach Denali from the south primarily originate from the Talkeetna Airport. Visual analysis of these data corroborates results of the DENA acoustic inventory (National Park Service, 2018a) which revealed that overflights are much less concentrated above the western areas of DENA. However, this may also be due to terrain shielding from the Alaska Range and the placement of the ADS-B loggers.

The second phase focused on low-level overflights (defined as flights up to 21,000 feet MSL) that were not cleaned of any flight type (i.e., major airlines, government flights, and survey flights). These results display maps of waypoints overlaid on DENA's Backcountry Management Plan soundscape zones. Seven maps were produced that segmented waypoints across altitude intervals that increase by 3,000 feet MSL. These maps show that most waypoints are below 12,000 feet MSL and that these waypoints are located over every soundscape management zone (Figures 3–6). The two highest altitude intervals, 15,001–18,000 feet MSL and 18,001–21,000 feet MSL, show distinct aircraft travel patterns near the peak of Mount Denali (Figures 7 and 8).

The third phase attempted to focus more specifically on low-level overflights that excluded government flights, straight-line flights, commercial airline flights, flights with a flightpath less than a mile in length, and survey flights. The dataset was cleaned of 587 government flights, 19,184 straight-line flights, 670 commercial airline flights, 91 flights with a flightpath less than a mile in length, and 2 survey flights. This left 19,154 flights, which is 48.26% of all the flights in Phase 1. The primary flight corridors displayed in Figure 1 (Phase 1 overflights) are also visible in Figure 10 (Phase 3 overflights).

Figure 11 displays density analysis and revealed that flight density is highest for the altitude interval of 0–500ft AGL. This finding is likely due to aircraft connecting the complex of airports within and adjacent to the DENA frontcountry, which is located in the "Day Use" soundscape zone. Also located within the "Day Use" zone is the Denali Park Road and Denali Visitor Center which is considered a frontcountry area because it receives high levels of terrestrial visitation.

Several analyses in this report focus on altitude of aircraft above ground level. Table 2, which displays number of waypoints within specific AGL altitude intervals, shows that the 3,001–3,500 feet AGL interval received the highest percentage of waypoints. Also, the following altitude intervals received high percentages of waypoints: 1,001–1,500 feet AGL; 1,501–2,000 feet AGL; 2,001–2,500 feet AGL; 2,501–3,000 feet AGL; 3,501–4,000 feet AGL; and 4,001–4,500 feet AGL. These findings show that most waypoints are between 1,000 and 4,500 feet AGL. These lower-level flights usually produce more intense noise than higher-level flights. In Advisory Circular 91-36D (2004), the FAA recommends pilots fly above 2,000 feet AGL over parks, wildlife refuges, and areas with wilderness characteristics; but this is a recommendation, not a regulation (Peterson et al., 2023).

Error associated with altitude is a limitation of this analysis (see the Methods section for more details). Negative AGL values were calculated but only represent 1.7% of the data (75,716 waypoints). Seven aircraft accounted for 87.97% of these waypoints. Figure 12 displays the traffic patterns of the <0 feet AGL tracks. There is a concentration of negative AGL altitude waypoints at the Denali National Park Airport which suggests some negative AGL waypoints may have been recorded while the aircraft was grounded at the airport. There is a second concentration of negative AGL waypoints in the southern part of the park which may have resulted from pilots landing on glaciers, which is in agreement with their CUA.

With certainty, the Alaska Range caused terrain shielding for ADS-B signals of flights at lower altitudes because the three loggers were deployed at relatively low elevation within the southern and eastern areas of the park. Figure 3 (Phase 2 waypoints up to 3,000 feet MSL) and Figure 15 (Phase 3 waypoints up to 5,250 feet MSL) display very few tracks north of the mountain range. However, higher altitude flights are displayed in Figure 2, which suggests terrain shielding likely obscures the observation of many flight segments and the majority of flights originating from the Kantishna Hills region of DENA.

Temporal patterns of flights were also examined. Table 5 shows that the percentage of flights across days of the week are consistent with the lowest percentage of flights occurring on Sundays (13.0%), Mondays (13.7%), and Tuesdays (13.9%). The highest percentage of flights occurred on Wednesdays (15.6%) and Saturdays (15.0%). Table 6 displays percentage of overflights across hours of the day, revealing that a significant number of flights occur from 11:00am to 3:00pm and from 4:00pm to 5:00pm. The mornings and the evenings are least impacted by low-level aircraft noise. Because the various ADS-B loggers do not collect data from completely overlapped spatial areas, there is some likelihood of bias in these temporal patterns due to spatial confounding.

Figures 26, 27, and 28 show sound sensitive areas which operators suggested as a voluntary no-fly zone (National Park Service, 2018b). This is an area all parties on the Denali Aircraft Overflights Advisory Council agreed worthy of enhancing natural sounds and limiting overflight noise impacts. This strategy is designed to reduce noise impacts in key areas of DENA. As seen in Figures 26, 27, and 28, there are flight patterns within the sound sensitive areas with the most overlap by flights at 2,501 to 5,000ft AGL altitudes.

In conclusion, this study produced results to further understand overflights at DENA at a fine spatial scale. This information can be used for planning and management purposes. This study serves as a resource for future research that intends to use more advanced analytics.

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National Park Service
U.S. Department of the Interior

Science Report NPS/SR—2025/220
https://doi.org/10.36967/2307459

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
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NPS 184/195998, February 2025